HEADQUARTERS
QUARTERMASTER RESEARCH & ENGINEERING COMMAND
U S ARMY

TECHNICAL REPORT
EP-143

A METHOD OF PREDICTING THE FREQUENCY DISTRIBUTION OF WINDCHILL

QUARTERMASTER RESEARCH & ENGINEERING CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

JANUARY 1961

NATICK, MASSACHUSETTS

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The reliability of the prediction chart is tested by frequency records from 34 additional stations. Deviations of actual windchill values from the predictions are, on the average, 20 windchill units greater than deviations in the model. The same general pattern of error deviation is observed.

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3. Meteorology
4. Meteorological data
5. North America
6. Temperature

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Jane Howe Westbrook
Geographer

Environmental Analysis Branch

Project Reference:
7-83-01-008

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FOREWORD

PREDICTION OF CLIMATIC CONDITIONS, AS ONE ELEMENT OF RISK, IS NOW WELL ESTABLISHED AS ONE OF THE PARAMETERS INVOLVED IN MILITARY OPERATIONS. BASED ON FREQUENCY DISTRIBUTION, PREDICTIONS OF ONE ELEMENT HAVE NOW BECOME STANDARD PRACTICE. THE PREDICTION OF TWO SIMULTANEOUSLY-OCCURRING ELEMENTS IS MORE RECENT. ALTHOUGH THE WINDCHILL CONCEPT DEPICTING THE COMBINATION OF TEMPERATURE AND WINDSPEED HAS BEEN IN USE FOR 20 YEARS, THIS IS THE FIRST ATTEMPT AT DEVELOPING A METHOD FOR PREDICTING ITS OCCURRENCE BASED ON FREQUENCY TABULATIONS.

IT IS POSSIBLE TO PREDICT THE PROBABILITY OF OCCURRENCE OF CRITICAL WINDCHILL LEVELS, BY UTILIZING THE RELATIONSHIP WHICH EXISTS BETWEEN WINDCHILL DERIVED FROM LONG-TERM TEMPERATURE AND WINDSPEED AVERAGES (THE WINDCHILL INDEX) AND A WINDCHILL FREQUENCY DISTRIBUTION OBTAINED FROM SIMULTANEOUS OCCURRENCES OF THE TWO ELEMENTS. PREDICTIONS CAN THUS BE MADE FOR ANY AREA IN THE WORLD WHERE TEMPERATURE AND WINDSPEED DATA ARE RECORDED AND ARE AVAILABLE AS LONG-TERM AVERAGES.

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ABSTRACT

EIGHT YEARS OF SIMULTANEOUS RECORDINGS OF JANUARY TEMPERATURE AND WINDSPEED FROM 20 NORTH AMERICAN STATIONS ARE USED IN THE DEVELOPMENT OF A METHOD FOR PREDICTING THE PERCENTAGE OF TIME WINDCHILL WILL LIE ABOVE OR BELOW A GIVEN VALUE. A WINDCHILL PREDICTION CHART IS CONSTRUCTED. IT COMBINES THE SIPLE NOMOGRAM, USED TO DERIVE THE WINDCHILL INDEX BASED ON AVERAGE TEMPERATURE AND WINDSPEED, AND THE PREDICTION MODEL BASED ON THE WINDCHILL FREQUENCIES. PREDICTION ERRORS (RANGE 0 - 240 WINDCHILL UNITS, WITH AVERAGE OF 52) PRODUCE A SKEWED DISTRIBUTION WITH 64 PERCENT OF THE ERRORS LESS THAN THE AVERAGE. ERRORS GREATER THAN AVERAGE ARE CONCENTRATED BETWEEN THE 5TH AND 30TH AND BEYOND THE 95TH PERCENTILES. MAGNITUDE OF ERROR INCREASES AS THE INDEX INCREASES.

THE RELIABILITY OF THE PREDICTION CHART IS TESTED BY FREQUENCY RECORDS FR 34 ADDITIONAL STATIONS. DEVIATIONS OF ACTUAL WINDCHILL VALUES FROM THE PREDICTIONS ARE, ON THE AVERAGE, 20 WINDCHILL UNITS GREATER THAN DEVIATIONS IN THE MODEL. THE SAME GENERAL PATTERN OF ERROR DEVIATION IS OBSERVED.

A METHOD OF PREDICTING THE FREQUENCY DISTRIBUTION OF WINDCHILL

1. Introduction

A. Purpose and method

This report deals with methods developed for predicting the probable frequency distribution of windchill in areas where only the monthly long-term averages of temperature and windspeed data are available. Windchill, a term first used by Siple, 1939(15), is thought by many investigators to be a more sensitive measure of cooling power than either temperature or windspeed data used separately.

Climatologists have long been handicapped by a lack of data suitable for use in heat-balance formulas, and are forced to rely on such data as are available. It is fortunate that data on temperature and wind, which govern the dry-cooling power of the atmosphere, are available. Temperature is the element observed at the most dense network of weather stations. A rapidly decreasing number of stations observe the other elements which would have to be considered in a complete heat-balance formula. While temperature and windspeed data are available for many stations, they are not usually tabulated in the most usable form.

The Siple-Passel formula, 1945(16), is used to establish the relationship which exists between windchill levels (computed from monthly averages of temperature and windspeed) - called the "windchill index" in this report - and windchill frequencies obtained from simultaneous recordings of temperature and windspeed arranged in bivariate classes. A graphic method is developed for determining an adjusted windspeed for each class interval, since wind classes were large and of various sizes in the summarized data available. The results of the method are tested against results obtained by using wind averages from the same period of record. The mid-mark of the temperature class and the adjusted windspeed of each class are used to determine the windchill for each bivariate class. Frequencies obtained from this method are tested against frequencies obtained from conversion of each bi-hourly simultaneous recording of temperature and windspeed from the same period and found to be reliable.

A statistical model, used as the predictor, is constructed using the records from 20 stations. Predictions at selected percentile levels are tested against the actual occurrences of windchill at the 20 stations used in constructing the model and are found to be reliable within acceptable limits. Further testing of randomly-chosen stations tended to substantiate the hypothesis that the percentage frequency occurrence of

WINDCHILL CAN BE PREDICTED WITHIN LIMITS NO GREATER THAN EITHER YEAR-TO-YEAR FREQUENCY VARIATIONS OR THOSE WHICH MAY OCCUR FROM ONE HOUR TO THE NEXT, OR BY MOVING TO A MORE WINDWARD OR LEEWARD SITE IN THE OBSERVATION AREA.

JANUARY RECORDS HAVE BEEN USED IN DEVELOPING THE METHOD. WHILE THE METHODS ARE APPLICABLE TO ANY MONTH, IT IS NOT KNOWN WHETHER OR NOT THE RESULTS OBTAINED WOULD BE COMPARABLE.

B. DEVELOPMENT AND APPLICATION OF THE WINDCHILL CONCEPT

FIRST APPLIED BY SIPLE IN 1939(15) TO GIVE A MEASURE OF THE RELATIVE COOLING POWER OF COMBINATIONS OF WINDSPEED AND LOW TEMPERATURE, THE TERM "WINDCHILL" HAS GAINED WIDE ACCEPTANCE BY MILITARY AND CIVILIAN AGENCIES, BOTH IN THE UNITED STATES AND ABROAD. THE WINDCHILL CONCEPT WAS INCORPORATED IN THE CLIMATE ZONE MAP SERIES, 1942(4) AND USED IN VARIOUS REPORTS OF THE ENVIRONMENTAL PROTECTION SECTION OF THE OQMG DURING THE EARLY 1940'S.

THE RESULTS OF THE EXPERIMENTS CONDUCTED IN ANTARCTICA, 1939-40, TOGETHER WITH THE EMPIRICAL FORMULA DEVELOPED, WERE PUBLISHED BY SIPLE AND PASSEL, 1945(16).

IN THEIR EXPERIMENTS (SOME 80 IN NUMBER), THE COOLING RATE WAS DETERMINED BY THE LENGTH OF TIME REQUIRED FOR A MEASURED QUANTITY OF WATER TO FREEZE AND GIVE OFF ITS LATENT HEAT OF FUSION. COMPARISONS WERE MADE BETWEEN THESE ATMOSPHERIC COOLING RATES AND A WINDCHILL SCALE ESTABLISHED. LOWER LIMITS OF PHYSICAL ENDURANCE WERE DETERMINED; AND LENGTH OF ELAPSED TIME BEFORE EXPOSED PORTIONS OF THE BODY TURNED WHITE OR ACTUALLY FROZE WERE RECORDED AT VARIOUS WIND VELOCITIES AND SUB-FREEZING TEMPERATURES. THE SIPLE-PASSEL FORMULA IS

$$K_0 = (\sqrt{v \times 100} + 10.45 - v) (33 - T_A)$$

WHERE:

K_0 = COOLING POWER OF THE ATMOSPHERE IN KILOGRAM CALORIES PER HOUR PER SQUARE METER

v = WIND VELOCITY IN METERS PER SECOND

T_A = TEMPERATURE OF THE AIR IN DEGREES CENTIGRADE /33°C. (OR 91.4°F.) IS SKIN TEMPERATURE UNDER CALM CONDITIONS, AND ASSUMES AN AVERAGE OUTGOING RADIATION AND AVERAGE CONVECTION./

THE FINDINGS OF OTHER INVESTIGATIONS WERE USED TO ARRIVE AT THE CONCLUSION REACHED. NOTHING MORE WAS CLAIMED FOR THE FORMULA THAN THE

ADVANCEMENT OF THE KNOWLEDGE OF THE COOLING POWER OF THE ATMOSPHERE. AS THE FORMULA STANDS, USING SKIN TEMPERATURE, IT IS APPLICABLE TO THOSE SITUATIONS WHERE MAN IS A FACTOR; IT IS NOT APPLICABLE TO INANIMATE OBJECTS PER SE. SUCH APPLICATIONS WOULD REQUIRE A SURFACE TEMPERATURE CORRECTION FACTOR.

THE TEMPERATURE-WINDSPEED CORRELATION MIGHT HAVE BEEN MADE WITH ANY ONE OF A NUMBER OF MATERIEL APPLICATIONS, SUCH AS HEATING REQUIREMENTS IN TENTS OR STATIONARY SHELTERS, AND HAS BEEN SO USED IN SUBSEQUENT TEST REPORTS. IN LITTLE AMERICA IT WAS NOTED THAT AT 400 WINDCHILL, THE SNOW SURFACE BECAME TACKY AND SOFT. SINCE THIS CONDITION WAS INDICATED AS "MIDSUMMER," IT CAN BE ASSUMED THAT SOLAR RADIATION WAS ALSO A CAUSATIVE FACTOR IN PRODUCING THE SOFT AND TACKY CONDITION. WHILE TEMPERATURE AND WINDSPEED ARE THE ONLY CLIMATIC ELEMENTS USED IN THE CALCULATIONS OF THE FORMULA, THERE IS EVERY INDICATION THAT THE INVESTIGATORS WERE WELL AWARE OF THE INFLUENCE OF SOLAR RADIATION DURING THAT PORTION OF THE YEAR WHEN IT WAS AN IMPORTANT FACTOR; "MIDSUMMER," "CLEAR SUNLIT DAY," OR "FOGGY OVERCAST DAY" ARE A PART OF THE DESCRIPTIVE TERMS USED, IN ADDITION TO THE CALCULATED WINDCHILL BASED ON WINDSPEED AND SHADE TEMPERATURE. THERE IS ALSO A STATEMENT AS TO THE PROBABLE DECREASE IN COOLING WITH BRIGHT SUNSHINE.

AS COLD CLIMATES HAVE CONTINUED TO PLAY AN IMPORTANT PART IN DEFENSE PLANNING IN THE POST-WAR PERIOD, TESTING OF ARMY EQUIPMENT HAS BEEN CARRIED ON IN MANY AREAS OF THE NORTHERN UNITED STATES, ALASKA, CANADA, AND GREENLAND. AT MANY OF THE TEST SITES, WIND AND TEMPERATURE DATA WERE RECORDED AND CORRELATED WITH PERFORMANCE OF A NUMBER OF TEST ITEMS. BRECKENRIDGE AND WOODCOCK, 1950(1) FROM THEIR TEST OF UNITED STATES, CANADIAN, AND BRITISH COLD-WEATHER UNIFORMS ON THE COPPER MAN AT FORT CHURCHILL, RECOMMENDED THAT "THE SIPLE 'WINDCHILL' INDEX BE CONSIDERED ROUGHLY APPLICABLE AS AN INDEX OF RELATIVE COOLING POWER OF ENVIRONMENTS FOR THE CLOTHED MAN, BUT THAT FOR SUCH APPLICATION THE UNITS BE CONSIDERED ARBITRARY RATHER THAN INDICATIVE OF BODY COOLING IN KG CALS/M^2/HR." THEY FURTHER STATE IN REFERENCE TO THE SIPLE WINDCHILL CHARTS, "THE CHARTS NEVERTHELESS INDICATE COOLING WHICH IS MORE IN LINE WITH SENSATION THAN THAT PREDICTED FROM EITHER TEMPERATURE OR WINDSPEED DATA ALONE."

SIMULTANEOUS RECORDINGS OF TEMPERATURE AND WINDSPEED WERE USED IN THE ORIGINAL SIPLE-PASSEL EXPERIMENTS, THE DEVELOPMENT OF THE FORMULA, AND CONSTRUCTION OF THE NOMOGRAM. HOWEVER, IT BECAME NECESSARY TO USE THE SUMMARIZED MONTHLY AVERAGES OF THE AVAILABLE INDIVIDUAL ELEMENTS IN ORDER TO MAP WINDCHILL AS DEPICTED IN NORTH AMERICA JANUARY AND JULY MAPS, 1943(3) AND THE CLIMATE ZONE MAPS, 1943-44(4), ON WHICH WINDCHILL ISOLINES WERE USED FOR THE ZONES BELOW FREEZING. THIS WAS ALSO THE METHOD USED IN THE MONTHLY MAPS OF CANADA, 1947(2). EACH PUBLICATION HAS BEEN BASED ON AVERAGE TEMPERATURE AND WINDSPEED DATA THAT WERE MORE VOLUMINOUS AND BETTER THAN THAT OF ITS PREDECESSORS. IN THE LATEST PUBLICATION ON THE SUBJECT

BY FALKOWSKI AND HASTINGS, 1958(7), 1,000 STATIONS WERE USED IN COMPILING THE NORTHERN HEMISPHERE MAP OF MEAN JANUARY WINDCHILL. THIS REPORT ALSO CONTAINS REFERENCES TO THE EARLIER REPORTS, WINDCHILL FACTOR TABLES, AND THE SIPLE WINDCHILL NOMOGRAM. THUS FOR 15 YEARS, ALL MAPPING OF THE WINDCHILL FACTOR HAS RELIED ON SUMMARIZED DATA COMBINED AND ASSUMED TO BE A TRUE AVERAGE WINDCHILL. THE VALIDITY OF USING AVERAGES OF TEMPERATURE AND WINDSPEED, AND ASSUMING IT TO BE A TRUE MEAN WINDCHILL, WAS QUESTIONED BY MANY, BUT THE NECESSARY DATA FOR TESTING THIS ASSUMPTION WERE UNAVAILABLE.

HOWEVER, WITH THE ESTABLISHMENT OF THE DATA PROCESSING UNIT OF THE WEATHER BUREAU AT ASHEVILLE IT BECAME FEASIBLE TO MANIPULATE SUFFICIENT DATA TO GIVE THE METHOD A FAIR EVALUATION. IN 1946 THE AUTHOR REQUESTED (THROUGH AIR WEATHER SERVICE) THE FREQUENCY TABULATIONS OF SIMULTANEOUS TEMPERATURE AND WINDSPEED DATA FOR THE ALASKA STATIONS. THIS FIRST SUMMARY INDICATED THAT WINDCHILL FROM AVERAGES DID NOT PRODUCE THE SAME MEAN VALUE AS WINDCHILL FROM FREQUENCIES. HOWEVER, THE AIR FORCE RECORDS WERE FOR SHORT PERIODS, IN SOME CASES INTERRUPTED, SO THEY WERE NOT SUITABLE FOR A REALLY THOROUGH INVESTIGATION OF THE METHOD.

IN THE MEANTIME, COURT, 1948(5) HAD MADE A CRITICAL ANALYSIS OF WINDCHILL, POINTING OUT THAT THE FORMULA NEGLECTED TO TAKE INTO ACCOUNT ALL AVENUES OF HEAT LOSS FROM THE HUMAN BODY. ALSO, HE AGAIN EMPHASIZED THE POSSIBILITY OF ERROR FROM COMBINING AVERAGES OF SEPARATE ELEMENTS IN LIEU OF SIMULTANEOUS RECORDINGS. HE ALSO POINTED OUT THE NEED FOR VERIFICATION OF IDENTICAL WINDCHILL VALUES ASSIGNED TO DIFFERENT WINDSPEED AND TEMPERATURE COMBINATIONS. THERE HAS BEEN NO ATTEMPT TO ANSWER THIS CRITICISM IN THIS REPORT. NEITHER HAS ANY ATTEMPT BEEN MADE TO RESOLVE WINDSPEEDS (AS GIVEN IN THE SUMMARIES) TO THE HEIGHT OF A MAN.

WITHIN THE PAST 3-YEAR PERIOD THERE HAVE BEEN TWO MAJOR COLLATION JOBS USING SIMULTANEOUS TEMPERATURE AND WINDSPEED RECORDS. IN THE FIRST, 5 YEARS OF TEMPERATURE AT VARIOUS WINDSPEEDS AND RELATIVE HUMIDITIES HAVE BEEN SUMMARIZED BY THE WEATHER BUREAU ON A MONTHLY BASIS FOR 117 FIRST-ORDER STATIONS IN THE UNITED STATES (21). IN THE SECOND, MONTHLY FREQUENCIES OF SIMULTANEOUS RECORDINGS OF TEMPERATURE AND WINDSPEEDS FOR 326 NORTHERN HEMISPHERE STATIONS WERE PREPARED BY THE ASHEVILLE WEATHER RECORDS CENTER (8). THESE DATA, IN MOST CASES, ARE FOR AT LEAST 8- OR 10-YEAR PERIODS. THESE TWO SOURCES, TOGETHER WITH THE 10 YEARS OF BI-HOURLY DATA FROM FORT CHURCHILL, CONSTITUTE THE DATA USED IN THIS REPORT FOR FORMULATING HYPOTHESES, CONSTRUCTING STATISTICAL MODELS, AND TESTING MODEL PERFORMANCE.

c. Frequency predictions of climatic elements

THE REQUIREMENT OF THE ARMED FORCES TO BE ABLE TO OPERATE IN ANY ENVIRONMENT AT ANY TIME AND PLACE HAS ENGENDERED A SERIES OF STUDIES TO DETERMINE THE EXTREMES OF ENVIRONMENT WHICH MAY BE ENCOUNTERED. THESE

STUDIES, USUALLY BASED ON A SINGLE ELEMENT, HAVE BEEN SUMMARIZED IN SUCH REPORTS AS THOSE OF SISSENWINE AND COURT, 1951(17), AND FURTHER ADVANCED FOR THE AIR FORCE GEOPHYSICS RESEARCH OFFICE, 1957(18). BASED ON PAST CLIMATIC OBSERVATIONS, FREQUENCY OF OCCURRENCE OF CRITICAL CONDITIONS HAS BEEN ESTABLISHED TO GIVE THE PROBABLE ELEMENT OF RISK INVOLVED. IN PROJECTING THE PROBABLE FREQUENCY OF OCCURRENCE IN AREAS WHERE FREQUENCY DATA ARE NOT AVAILABLE, NOTABLE ACHIEVEMENTS HAVE BEEN MADE BY SPREEN, 1956(19), LACKEY, 1957(10), 1958(11), AND 1960(12), AND WESTBROOK, 1958(23). THIS LED TO THE IDEA THAT IT MIGHT BE POSSIBLE TO PREDICT THE PROBABLE FREQUENCY OF TWO ELEMENTS COMBINED AS A SINGLE ENTITY, E.G., WINDCHILL.

FOR THIS PURPOSE IT IS ASSUMED THAT THE SIPLE WINDCHILL FORMULA IS ACCEPTABLE FOR THE TEMPERATURE-WINDSPEED COMPLEX, JUST AS DEW-POINT OR WET-BULB TEMPERATURES ARE ACCEPTABLE FOR THE TEMPERATURE-HUMIDITY COMPLEX. LABORATORY AND FIELD EXPERIMENTS WILL TEST AND VERIFY THE IMPORTANCE OF WINDCHILL ON MAN, IN THE NUDE OR WITH COMBAT UNIFORM. IT IS REALIZED THAT IT WILL TAKE MANY MORE EXPERIMENTS SUCH AS THE CLIMATIC CHAMBER STUDY, BY IAMPIETRO, 1958(9) AND THE EXPERIMENTAL WORK IN PROGRESS AT MAYNARD TEST SITE*, (ESTABLISHED IN 1959) BEFORE ANY INDEX OF COOLING POWER CAN BE VERIFIED OVER THE ENTIRE RANGE OF CONDITIONS ENCOUNTERED IN ACTUAL OPERATIONS IN THE FIELD. THE POSSIBLE APPLICATION OF THE WINDCHILL FORMULA TO PERFORMANCE PREDICTION OF MAN-OPERATED EQUIPMENT IN ARCTIC AREAS WAS CONSIDERED REASON ENOUGH FOR REOPENING AN EVALUATION AND PREDICTION STUDY OF WINDCHILL.

2. PRELIMINARY INVESTIGATION OF WINDCHILL PREDICTION

EIGHT STATIONS WERE SELECTED FROM THE 117 STATIONS IN THE WEATHER BUREAU SUMMARIES (21), MENTIONED ABOVE, TO TEST THE FEASIBILITY OF A FREQUENCY PREDICTION METHOD. AS HAD BEEN DONE IN ALL PREVIOUS WINDCHILL MAPPING STUDIES, LONG-TERM AVERAGES OF TEMPERATURE AND WINDSPEED WERE USED TO COMPUTE THE WINDCHILL INDEX, USING THE SIPLE WINDCHILL TABLE (3). JANUARY DATA WERE USED IN THE MODEL SINCE IT IS ASSUMED THAT JANUARY WOULD PROBABLY PRODUCE THE HIGHEST WINDCHILL INDICES. TABLE I GIVES PERTINENT STATISTICS FROM THE LONG-TERM AVERAGES FOR THE 8 STATIONS.

SEVERAL STEPS WERE NECESSARY BEFORE THE DATA FROM THE WEATHER BUREAU SUMMARIES (21) COULD BE USED. WINDSPEEDS HAD TO BE ADJUSTED TO A MORE REPRESENTATIVE AVERAGE FOR EACH WINDSPEED CLASS. MID-MARK FOR TEMPERATURE AND THE ADJUSTED WINDSPEEDS WERE THEN CONVERTED, USING SIPLE WINDCHILL TABLES, TO THE APPROPRIATE WINDCHILL VALUE FOR THE BIVARIATE CLASSES. WINDCHILL INCIDENTS IN EACH 5-DEGREE TEMPERATURE AND ADJUSTED MID-POINT OF WINDSPEED CLASS WERE CONVERTED TO PERCENTAGE AND THE CUMULATIVE FREQUENCIES ESTABLISHED.

A. ADJUSTED WINDSPEEDS

WIND IS THE MORE SENSITIVE ELEMENT IN THE WINDCHILL FORMULAE; THIS IS BECAUSE WINDCHILL INCREASES VERY RAPIDLY FROM CALM TO 1 MILE PER

*MAYNARD QM TEST ACTIVITY, MAYNARD, MASS.

TABLE I
8 STATIONS CONSIDERED FOR PRELIMINARY WINDCHILL MODEL

STATION	AVERAGE JANUARY TEMP. (°F)	AVERAGE JANUARY WINDSPEED (MPH)	WINDCHILL INDEX (KG CAL/M2/HR)*
DULUTH	10.3	12.3	1275
MINNEAPOLIS	14.6	10.5	1175
BILLINGS	22.9	12.6	1090
CHEYENNE	25.5	14.2	1070
CHICAGO	24.9	10.9	1020
SPOKANE	24.9	8.2	955
ST. LOUIS	33.3	12.6	920
DENVER	28.7	9.6	930

*ROUNDED TO THE NEAREST MULTIPLE OF 5

NOTE: THE ABOVE DATA, ALONG WITH SELECTED PERCENTILE FREQUENCY LEVELS OF WINDCHILL, WERE USED IN CONSTRUCTING THIS FIRST TRIAL MODEL. THE WINDCHILL INDEX WAS PAIRED WITH INDIVIDUAL FREQUENCY LEVELS OF WINDCHILL AND A LEAST SQUARES TREND OBTAINED.

HOUR, AFTER WHICH POINT IT CONTINUES TO INCREASE, BUT AT A DECREASING RATE. IT IS THUS IMPORTANT TO HAVE THE WINDSPEEDS AS NEARLY CORRECT AS POSSIBLE. THE WINDSPEED CLASSES IN THE SUMMARIZED DATA WERE NOT ONLY NON-UNIFORM, BUT RATHER LARGE FOR THE PURPOSE IN MIND: 0-4, 5-14, 15-24 AND OVER 25 MILES PER HOUR. EACH CLASS INTERVAL IS ONLY A SEGMENT, REGARDLESS OF THE MAGNITUDE OF THE TOTAL DISTRIBUTION. IT IS THUS POSSIBLE TO PRODUCE A CUMULATIVE PERCENTAGE FREQUENCY WIND CURVE FOR EACH STATION, AND DETERMINE THE AVERAGE WINDSPEED, OR THE ADJUSTED AVERAGE WINDSPEED FOR EACH CLASS INTERVAL. BY THIS METHOD, CUMULATIVE FREQUENCIES WERE PLOTTED AGAINST THE BOUNDARY VALUES OR END POINTS OF THE WIND CLASS INTERVALS IN IDENTICAL FORMATS FOR EACH STATION, USING WINDSPEEDS AS THE X AXIS AND PERCENTAGE FREQUENCIES AS THE Y AXIS. FOR THE 100TH PERCENTILE, THE ALL-TIME MAXIMUM WINDSPEED FOR EACH STATION WAS USED. THERE WERE RELATIVELY FEW INSTANCES OF WIND ABOVE THE 25-MILE LIMIT AT ANY OF THE STATIONS

SELECTED, BUT WITH ONLY 4 KNOWN POINTS, A 5TH AT THE 100TH PERCENTILE PRODUCED A BETTER CURVE. THE AMOUNT OF CALM, INCLUDED IN THE FIRST CLASS INTERVAL, WAS UNKNOWN, WHICH MADE IT IMPOSSIBLE TO PROPERLY ASSESS - WITH THE PRECISION NECESSARY - THE LOWER SECTION OF THE CURVE IN THE VERY AREA WHERE AN ACCURATE READING WAS THE MOST VITAL FOR PROPER WINDCHILL VALUES. THE WIND CURVES FOR 3 STATIONS - PHOENIX, CHATTANOOGA, AND AMARILLO - WITH WIDE DIFFERENCES IN AVERAGE WINDSPEEDS, ARE USED TO ILLUSTRATE THE METHOD AND ASSESS THE ACCURACY OBTAINED (FIG. 1).

THE ACCURACY OF THE WIND CURVE WAS ASSESSED BY A COMPARISON OF THE MEAN WINDSPEED OBTAINED BY THE GRAPHIC METHOD AND THAT OBTAINED BY THE MID-MARK METHOD BY USING THE FORMULA

$$\bar{X} = \frac{1}{N} \sum_{I=1}^{N} FI \; XI$$

WHERE:

FI IS THE FREQUENCY OF THE CLASS WHOSE MID-VALUE IS XI

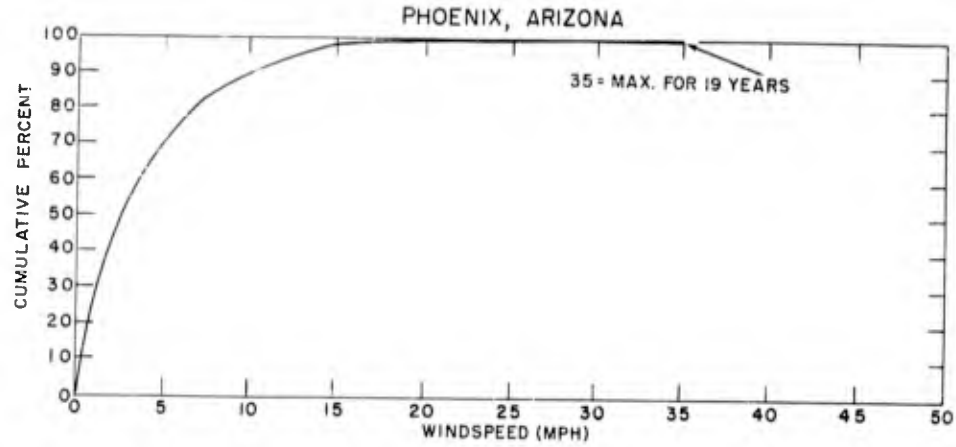
N IS THE NUMBER OF CLASSES

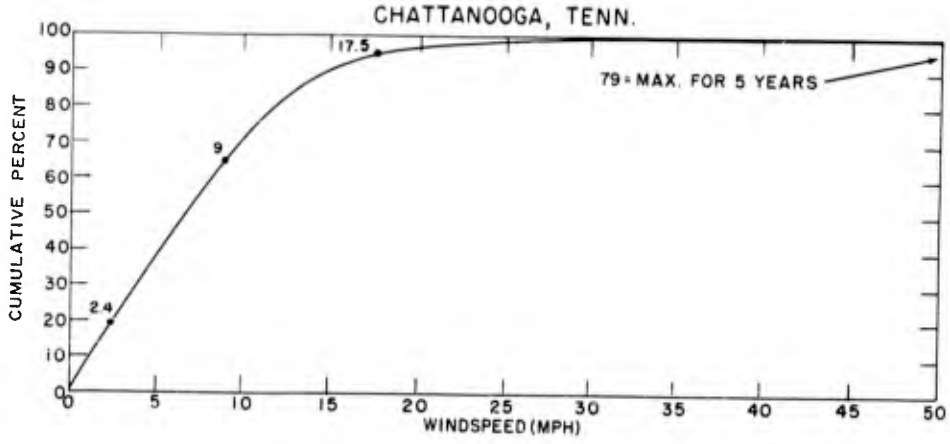
$N = \sum_{I=1}^{N} FI$ THE TOTAL FREQUENCY

THE ASSUMPTION WAS MADE THAT EACH STATION HAD 100 OBSERVATIONS AND THE PERCENTAGE OF OBSERVATIONS WITHIN EACH CLASS WOULD CORRESPOND TO THE FI. THE XI WOULD IN TURN BE THE ADJUSTED WINDSPEED FOR EACH CLASS INTERVAL FOR THE GRAPHIC METHOD, AND THE MID-MARK FOR THE SECOND (MID-MARK) METHOD. AN ARITHMETIC MEAN WAS THEN OBTAINED OF THE YEARLY AVERAGES FOR THE 5 YEARS CORRESPONDING TO THE PERIOD FOR WHICH THE FREQUENCY TABULATIONS WERE AVAILABLE. TABLE II SHOWS A COMPARISON OF EACH OF THE METHODS FOR THE 3 STATIONS AND A SUMMARY OF RESULTS OBTAINED.

TO DETERMINE THE AVERAGE WINDSPEED FOR A CLASS INTERVAL FROM THE STATION WIND CURVE, (SEE FIG. 1 - AMARILLO) A VERTICAL LINE WAS DROPPED FROM THE END POINT OF THE CLASS INTERVAL TO INTERCEPT A HORIZONTAL LINE FROM THE BEGINNING OF THE INTERVAL. THE MID-POINT ON THE VERTICAL LINE WAS DETERMINED BY PROPORTIONAL DIVIDERS AND A HORIZONTAL LINE DRAWN FROM THAT POINT TO CONNECT WITH THE WIND CURVE. THE POINT OF INTERSECTION ON THE WIND CURVE INDICATES THE ADJUSTED WINDSPEED FOR THE CLASS INTERVAL, AND IS READ ON THE WINDSPEED SCALE DIRECTLY BELOW THE INTERSECTION.

FOR PHOENIX, THE ADJUSTED AVERAGES FOR THE CLASS INTERVALS PRODUCED AN AVERAGE WINDSPEED OF 3.635 MPH FOR THE 5 YEARS OF THE FREQUENCY





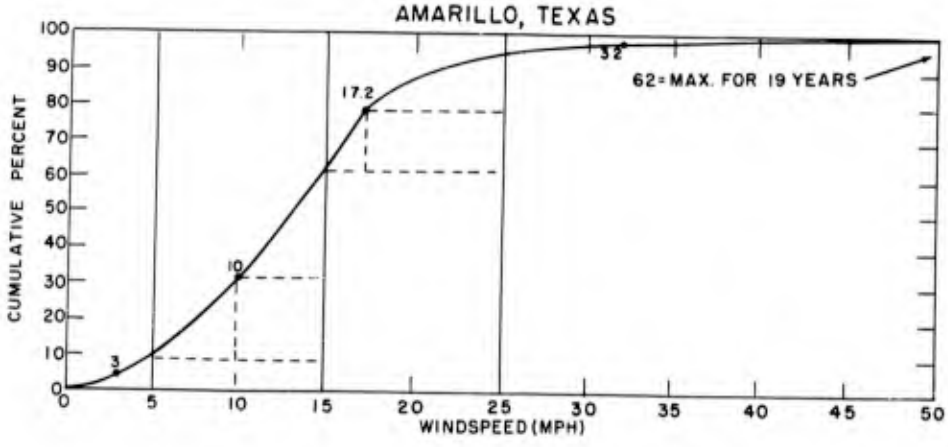


FIGURE 1: CUMULATIVE PERCENTILE DISTRIBUTION OF WINDSPEED (MPH) AT 3 STATIONS

TABLE II: COMPARISON OF GRAPHIC AND MID-MARK METHODS OF OBTAINING AVERAGE WINDSPEEDS OF CLASS INTERVALS AT 3 STATIONS

Graphic Method				Mid-Mark Method			
Wind Class MPH	FI	XI	FI XI	Wind Class MPH	FI	XI	FI XI
A. Phoenix							
0- 4	69.5	1.5	104.25	0- 4	69.5	2.5	161.25
5-14	29.0	7.7	223.30	5-14	29.0	10.0	290.00
15-24	1.0	20.0	20.00	15-24	1.0	20.0	20.00
Above 25	.5	32.0	16.00	Above 25	.5	30.0	15.00
Σ	100.0		363.55	Σ	100.0		486.25
$\bar{X} = \frac{363.55}{100.0} = 3.64$				$\bar{X} = \frac{486.25}{100.0} = 4.86$			
B. Chattanooga							
0 -4	38.5	2.4	92.40	0- 4	38.5	2.5	96.25
5-14	53.0	9.0	477.00	5-14	53.0	10.0	530.00
15-24	8.0	17.5	140.00	15-24	8.0	20.0	160.00
Above 25	.5	35.0	17.50	Above 25	.5	35.0	17.50
Σ	100.0		726.9	Σ	100.0		803.75
$\bar{X} = \frac{726.9}{100.0} = 7.27$				$\bar{X} = \frac{803.75}{100.0} = 8.04$			
C. Amarillo							
0- 4	9.0	3.0	27.00	0- 4	9.0	2.5	22.50
5-14	53.0	10.0	530.00	5-14	53.0	10.0	530.00
15-24	33.5	17.2	576.20	15-24	33.5	20.0	670.00
Above 25	4.5	32.0	144.00	Above 25	4.5	36.5	164.25
Σ	100.0		1277.2	Σ	100.0		1386.75
$\bar{X} = \frac{1277.2}{100.0} = 12.77$				$\bar{X} = \frac{1386.75}{100.0} = 13.87$			

SUMMARY OF AVERAGE WINDSPEEDS (M.P.H.) AT THREE STATIONS

	Phoenix	Chattanooga	Amarillo
Long-term Average	4.2	7.6	13.1
5-Year Average (Weather Bureau Data)	3.64	7.26	12.76
5-Year Average Graphic Method	3.64	7.27	12.77
5-Year Average Mid-mark Method	4.86	8.04	13.87

TABULATIONS; THIS COMPARES MOST FAVORABLY WITH THE 3.64 SPEED PRODUCED BY AVERAGING EACH OF THE INDIVIDUAL 5-YEAR AVERAGES. THE ALTERNATIVE (MID-MARK) METHOD (4.86) EXCEEDS THE GRAPHIC METHOD BY 1.22 MILES PER HOUR. THE AVERAGE WINDSPEED BY MID-MARK METHOD ACTUALLY EXCEEDS THE LONG-TERM MEAN FOR EACH OF THE 3 STATIONS, ALTHOUGH THE 5-YEAR AVERAGE IS IN EACH CASE SOMEWHAT LESS.

A STUDY OF THE 3 STATIONS ILLUSTRATED GIVES OTHER INTERESTING COMPARISONS. FOR A LOW-AVERAGE-WINDSPEED STATION LIKE PHOENIX, THE ADJUSTED SPEED BY WINDSPEED CLASSES IS VERY DIFFERENT FROM THAT OF A STATION WITH A RELATIVELY HIGH AVERAGE WINDSPEED LIKE AMARILLO. CHATTANOOGA, A MID-RANGE WINDSPEED STATION, GIVES STILL DIFFERENT ADJUSTED WINDSPEED FOR EACH WIND CLASS. THE ERROR AT PHOENIX WAS GREATER BY THE MID-MARK METHOD BY 33 1/2% $\frac{4.86}{3.64} = 1.335$ AND $1.335 - 1.00 = .335$

BY SIMILAR METHOD THE ERROR AT PHOENIX BY THE GRAPHIC METHOD WAS $\frac{3.635}{3.640} = .0998 - 1.00 = -.002$ OR ABOUT 1/5 OF 1 PERCENT ERROR.

FROM A STUDY OF THESE 3 STATIONS IT DOES NOT FOLLOW THAT THE ERROR DECREASES WITH INCREASES IN AVERAGE WINDSPEED, AS THE RESULTS WOULD BE DEPENDENT ON THE DISTRIBUTION AND WOULD NEED TO BE RESOLVED ON AN INDIVIDUAL STATION RECORD. IT CAN THEN BE SEEN THAT WHERE ONLY BIVARIATE SUMMARIZATIONS OF TEMPERATURE AND WINDSPEED DATA ARE AVAILABLE FOR ESTIMATING THE WINDCHILL FOR THE BIVARIATE CLASSES, IT IS ESSENTIAL THAT THE MORE SENSITIVE ELEMENT (WINDSPEED) IN THE CALCULATION BE ESTIMATED AS ACCURATELY AS POSSIBLE.

THE ADJUSTED WINDSPEEDS FOR THE 8 STATIONS SELECTED FOR THE PRELIMINARY INVESTIGATION ARE GIVEN IN TABLE III.

B. WINDCHILL VALUES FOR THE 8-STATION MODEL

THE MID-MARK FOR EACH 5F° TEMPERATURE CLASS, AND THE ADJUSTED MEAN WINDSPEED OF EACH CLASS WERE USED AS THE VALUES FOR EACH BIVARIATE CLASS TO CONVERT TO WINDCHILL VALUES USING THE SIPLE WINDCHILL CONVERSION FORMULA (16). THESE VALUES WERE NEXT RANKED FROM LEAST TO GREATEST. AFTER CONVERTING THE NUMBER OF INCIDENTS TO PERCENTAGE FIGURES, A CUMULATIVE FREQUENCY DISTRIBUTION OF WINDCHILL WAS MADE FOR EACH OF THE 8 STATIONS AS SHOWN IN TABLE IV. IT WILL BE NOTED THAT THE 50TH PERCENTILE IS IN ALL CASES LESS THAN THE INDEX; THIS POINTS UP ONE OF THE CRITICISMS WHICH HAS BEEN RAISED IN REGARD TO THE USE OF LONG-TERM MEANS FOR SPECIFYING WINDCHILL AND ASSUMING IT TO BE A TRUE MEAN.

C. PREDICTION OF PERCENTAGE FREQUENCY BY LEAST SQUARES

THE METHOD OF LEAST SQUARES WAS USED IN DEVELOPING THE RELATIONSHIP BETWEEN THE WINDCHILL INDEX OBTAINED FROM LONG-TERM AVERAGES OF

TABLE III
ADJUSTED WINDSPEEDS IN RELATION TO
STANDARD CLASS INTERVALS

Class Interval / Station	0-4	5-14	15-24	25 and Over
Duluth	2.4	9.4	18.5	29.0
Minneapolis	2.2	8.5	17.0	27.0
Billings	2.0	9.4	18.2	26.5
Cheyenne	2.1	9.5	18.0	30.25
Chicago	2.5	10.2	16.6	27.0
Spokane	2.0	8.2	16.7	27.0
St. Louis	2.2	9.0	17.2	26.0
Denver	2.2	7.8	17.5	30.0

temperature and windspeed, and the actual frequencies from the 5-year period. Predictions were made for the least and the greatest windchill to be expected and for each intervening 10th percentile. It was noted that percentage frequencies between the 20th and the 80th percentile could be predicted with a good degree of accuracy; however, the lower extremes tended to be under-predicted, and the upper extremes were over-predicted. This indicated that the best trend lines would be curvilinear. The prediction method using an index of long-term averages did show possibilities, however, and it was decided to expand the area from which the sample was drawn and to refine the method.

3. The 20-station model

A. Method and source of data

It was decided to expand the area to all of North America. Twenty samples (see map, Fig. 2) were drawn for the second regression model. Even in January, which would again be used, it would thus be possible to obtain stations with fairly high average temperature from Florida and California; and Alaska and Northern Canada would furnish the extreme cold temperatures. As wind is generally randomly distributed in relation to

TABLE IV
CUMULATIVE FREQUENCY DISTRIBUTION OF WINDCHILL LEVELS FOR 8 STATIONS

Cum. %	Duluth (1275)*	Minneapolis (1175)	Billings (1090)	Cheyenne (1070)	Chicago (1020)	Spokane (955)	St. Louis (920)	Denver (930)
100	2200	1850	2050	1970	1750	1640	1430	1480
90	1710	1520	1570	1210	1250	1220	1090	1080
80	1570	1360	1390	1170	1150	1050	1040	990
70	1450	1270	1190	1120	1040	980	980	930
60	1340	1200	1130	1040	990	950	910	860
50	1240	1120	1040	940	950	920	870	790
40	1170	1070	950	900	920	870	820	750
30	1120	1030	880	850	880	820	760	710
20	1040	970	820	790	830	790	670	640
10	920	870	720	700	720	670	560	555
0	347	291	231	236	319	236	175	152

*WINDCHILL INDEX IS GIVEN IN PARENTHESES UNDER EACH STATION.

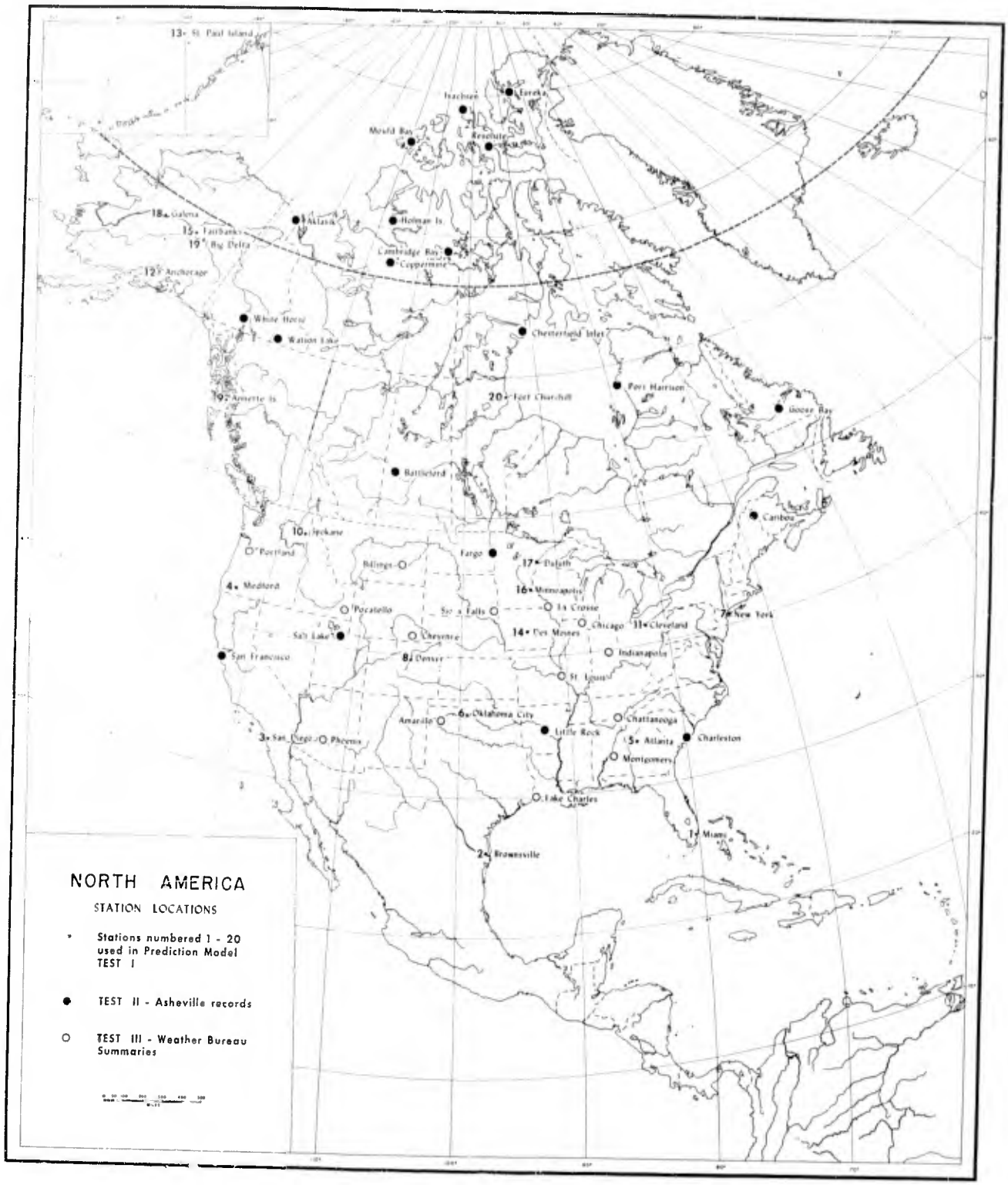


FIGURE 2: NORTH AMERICA - LOCATION MAP OF STATIONS USED IN MODEL AND IN TESTING

TEMPERATURE, A WIDE RANGE OF WINDCHILL FREQUENCIES WAS THUS AVAILABLE. IT WAS ALSO POSSIBLE TO MORE OR LESS PAIR STATIONS: WARM STATIONS WITH BOTH HIGH AND LOW WINDSPEEDS SUCH AS MIAMI AND SAN DIEGO, AND COLD STATIONS WITH BOTH HIGH AND LOW WINDSPEEDS SUCH AS FORT CHURCHILL AND FAIRBANKS. THE COMPLETE LIST SELECTED, WITH AVERAGE TEMPERATURE, WINDSPEED AND RESULTANT WINDCHILL INDICES FOR BOTH THE LONG-TERM PERIOD AND THE SHORTER PERIOD OF THE FREQUENCY TABULATIONS, IS GIVEN IN TABLE V. WHILE THERE IS SOME VARIATION BETWEEN THE LONG- AND SHORT-TERM WINDCHILL INDEX, THE DIFFERENCES ARE SLIGHT, WITH BOTH PLUS AND MINUS DEVIATIONS.

THE FREQUENCY DATA USED IN THIS MODEL WERE SELECTED FROM THE BIVARIATE SUMMARIES, WHICH HAD BEEN PREPARED (AT THE REQUEST OF THE ENVIRONMENTAL PROTECTION RESEARCH DIVISION OF THIS COMMAND) BY THE DATA PROCESSING UNIT AT ASHEVILLE (8). IN THESE SUMMARIES, TEMPERATURE WAS IN 5F° BREAKDOWNS (AS IN THE WEATHER BUREAU SUMMARIES FOR THE UNITED STATES) BUT WINDSPEED CLASSES WERE ACCORDING TO THE BEAUFORT CLASSIFICATION; THIS DOUBLED THE NUMBER OF POSSIBLE CLASSES (8, INSTEAD OF 4). ALL RECORDS WERE FROM 8 TO 10 YEARS IN DURATION, BUTVARIED IN NUMBER OF DAILY OBSERVATIONS.

B. WINDCHILL FREQUENCIES

AVERAGE WIND PER CLASS INTERVAL WAS AGAIN DETERMINED, AS IN THE CASE OF THE 8-STATION MODEL, BY DRAWING CUMULATIVE FREQUENCY CURVES. BECAUSE THE FREQUENCY OF CALM CONDITIONS HAD BEEN RECORDED, THE LOWER END OF THE CURVE COULD BE DRAWN WITH FAR MORE PRECISION. THE WIND CLASSES WERE:

CALM 1-3 4-7 8-12 13-18 19-24 25-46 > 46 MPH

WITH AN ADDITIONAL CLASS OF OVER 46 MPH, IT WAS UNNECESSARY TO RELY ON THE LONG-TERM EXTREME WIND, AS HAD BEEN DONE WITH THE EARLIER CURVES. MORE WIND CLASSES GAVE MORE POINTS THROUGH WHICH TO DRAW THE CURVES, PRODUCING GREATER ACCURACY THROUGHOUT THE CURVE.

A WINDCHILL FACTOR TABLE WAS CALCULATED FOR EACH TENTH-OF-A-MILE BREAKDOWN OF WINDSPEED, TO FACILITATE THE WORK OF CONVERSION TO THE WINDCHILL INDEX (TABLE IX, APPENDIX).

AS IN THE PRELIMINARY INVESTIGATION, WINDCHILL FREQUENCY WAS DETERMINED: FIRST, FOR EACH BIVARIATE CLASS BY USING THE ADJUSTED WINDSPEED AND THE MID-MARK OF THE TEMPERATURE CLASS, AND THEN BY REARRANGING THE WINDCHILL VALUES IN PROPER SEQUENCE. IT WAS POSSIBLE TO USE THE PERCENTAGES ALREADY CALCULATED BY MACHINE TABULATION BY MOVING THEM ALONG WITH THE WINDCHILL VALUES TO COMPLETE THE CUMULATIVE PERCENTAGE FREQUENCY DISTRIBUTION OF WINDCHILL. A SUMMARY OF THE FREQUENCIES FOR THE 20 STATIONS IS SHOWN AT VARIOUS PERCENTAGES IN SECTION A OF TABLE VI.

TABLE V
PERIOD-OF-RECORD AND LONG-TERM TEMPERATURE AND WINDSPEED AVERAGES AND WINDCHILL INDICES FOR 20-STATION MODEL

Station	Period of Record* Data Averages		Windchill Index**	Long-term Averages		Windchill Index**
	Temp (°F)	Wind (mph)		Temp (°F)	Wind (mph)	
1. Miami	67.9	10.1	355	68.5	13.4	370
2. Brownsville	63.5	13.2	445	60.5	12.1	485
3. San Diego	53.7	6.2	510	54.9	5.6	480
4. Medford	36.5	4.8	700	37.2	4.7	685
5. Atlanta	45.9	11.5	705	44.6	11.5	725
6. Oklahoma City	37.5	15.9	895	37.1	15.7	900
7. New York	36.0	14.1	900	29.1	13.7	1005
8. Denver	29.3	9.4	920	28.7	9.6	935
9. Annette Is.	31.9	12.3	940	34.6	14.3	925
10. Spokane	24.2	8.3	970	24.9	8.2	955
11. Cleveland	30.6	13.1	970	28.5	12.3	990
12. Anchorage	10.2	4.8	1035	13.0	5.2	1020
13. St. Paul Is.	27.4	18.0	1095	26.4	19.5	1130
14. Des Moines	21.6	12.7	1110	24.0	12.4	1065
15. Fairbanks	-12.1	2.6	1145	-9.8	3.3	1180
16. Minneapolis	13.3	11.4	1210	14.6	10.5	1170
17. Duluth	7.5	13.3	1345	10.3	12.3	1280
18. Galena	-12.0	6.0	1385	-9.5	6.0	1350
19. Big Delta	-5.8	12.2	1530	-5.0	17.0	1625
20. Churchill	-13.6	15.3	1735	-18.0	14.9	1800

*Period of record is the 8 or 10 years of Asheville collated data.
**In this report "windchill index" is the windchill obtained from averages of temperature and windspeed.

TABLE VI

COMPUTED WINDCHILL INDICES, FREQUENCIES, AND AVERAGES FOR 20-STATION MODEL

	Station	Windchill Index PFD*	Least .01%	1%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	99%	Most 99.9%	Windchill Average PFD*
	A. Percentile Distribution of Actual Windchill																	
1.	Miami	355	60	150	200	210	230	260	280	320	330	360	440	530	610	740	980	375
2.	Brownsville	445	60	150	220	240	280	300	340	380	400	470	550	660	750	990	1170	410
3.	San Diego	510	50	200	300	340	390	430	450	460	490	520	540	580	640	730	890	485
4.	Medford	700	200	280	300	330	370	430	580	650	690	720	790	860	910	1050	1340	610
5.	Atlanta	705	150	280	380	430	490	560	600	670	730	810	860	940	1000	1130	1230	685
6.	Oklahoma City	895	170	370	480	540	650	730	810	870	910	980	1070	1180	1310	1460	1640	875
7.	New York	900	240	410	550	610	670	750	820	880	900	980	1040	1130	1220	1350	1470	870
8.	Denver	920	190	390	520	590	660	750	810	860	910	980	1060	1190	1280	1470	1560	880
9.	Annette Is	940	320	360	550	660	780	810	870	890	910	970	1040	1190	1300	1390	1650	765
10.	Spokane	970	420	460	600	660	750	790	850	890	940	970	1040	1120	1210	1460	1640	910
11.	Cleveland	970	310	410	600	660	750	820	900	960	980	1060	1130	1220	1280	1400	1640	955
12.	Anchorage	1035	380	450	500	550	650	750	810	890	970	1040	1110	1240	1360	1550	1850	910
13.	St. Paul Is	1095	400	470	640	800	900	980	910	1040	1070	1100	1220	1370	1470	1560	1660	1015
14.	Des Moines	1110	270	520	720	810	890	950	970	1050	1120	1200	1300	1430	1500	1660	1830	1110
15.	Fairbanks	1145	380	550	600	660	770	840	910	980	1010	1110	1210	1320	1430	1640	2020	1020
16.	Minneapolis	1210	400	670	810	880	970	1040	1080	1150	1220	1290	1400	1490	1570	1750	1890	1190
17.	Duluth	1345	500	690	880	980	1050	1130	1210	1270	1340	1430	1560	1730	1820	2010	2140	1305
18.	Galena	1385	450	550	660	730	870	980	1060	1140	1270	1380	1480	1650	1730	1960	2220	1195
19.	Big Delta	1530	450	550	660	860	1020	1130	1220	1310	1400	1500	1650	1840	1950	2140	2330	1330
20.	Churchill	1735	550	990	1220	1300	1450	1550	1600	1690	1750	1890	1980	2060	2120	2230	2400	1700
	B. Group Averages of Indices, Percentile Levels, and Station Averages																	
	20-Sta Avg	995	298	445	570	642	735	799	854	918	967	1038	1124	1232	1323	1484	1678	930
	1st 10-Sta Avg	734	186	305	410	461	527	581	641	681	721	776	843	938	1023	1177	1357	686
	2nd 10-Sta Avg	1256	409	585	729	823	932	1017	1067	1148	1203	1300	1404	1535	1623	1790	1996	1173
	1st 5-Sta Avg	543	104	212	280	310	352	396	450	496	528	576	633	714	782	928	1122	513
	2nd 5-Sta Avg	925	268	398	540	612	702	766	832	878	914	998	1050	1162	1264	1426	1592	860
	3rd 5-Sta Avg	1071	348	480	612	696	792	868	900	984	1030	1102	1194	1316	1408	1562	1800	1020
	4th 5-Sta Avg	1441	470	690	842	950	1072	1166	1234	1312	1396	1498	1614	1754	1832	2018	2196	1344

*PFD = Period of Frequency Data

NOTE: These tables, all computed from the Asheville Summaries, and used as plotting points in establishing the prediction chart, have other important uses. For instance, by comparison of the 50% with the index it can be noted that at every station half of time windchill values were less than the index. With the single exception of Miami, averages were also less than the index. A comparison of the least and most columns would give the windchill range Miami 60-980, New York 240-1470, Spokane 420-1640, Churchill 550-2400. Since these are the actual windchill frequencies, they are used to establish plus or minus deviations from the prediction at any percentile level.

C. Percentile Distribution of Actual Windchill

All of the computed windchill frequencies for a given percentile were plotted against the windchill index based on the period of the record for each of the 20 stations (Section A, Table VI). An arithmetic average of all 20 frequency counts for the percentile was first made and plotted against the average of the 20 indices, followed in like manner by averages of the upper 10 and then the lower 10 stations. Finally, groups of 5 were averaged and plotted (Section B, Table VI). With these 7 reference points as guides, in addition to the scatter diagram of original data, the curve for each percentile was drawn, Ezekiel, 1941(6). Before the individual curves were accepted for final inclusion in a combined percentile chart, they were tested with the actual data to produce a curve with deviations at a minimum.

D. Measure of Central Tendency and Windchill Range

It is now possible to answer some of the questions that had been raised in regard to the significance of the windchill index obtained from long-term means of temperature and windspeed. It is possible to establish the relationship which exists between the index and both the 50th percentile and the mean windchill obtained from the frequency tabulations. It is possible to establish the relationship between the index and the windchill range obtained from the frequency data and to establish upper and lower limits of expectancy.

(1) Relationship of the Mean and the 50th Percentile of the Frequency Data to the Windchill Index

The mean of the windchill obtained by converting individual simultaneous recordings of temperature and windspeed deviates from the windchill index obtained from the average temperature and average windspeed for the same period of record. This deviation may be significant, not from the 100 (more or less) windchill units involved, but from the standpoint of trends which can be established.

From Fort Churchill test station, where bi-hourly temperature and windspeed had been converted to windchill units and so recorded, an average of these windchill values was less than for the windchill index based on the identical 10-year period. Year-by-year averages also remained consistently less than the year-by-year indexes, as show in Table VII.

To test for this relationship at stations other than Fort Churchill, 13 stations with available yearly averages of temperature and windspeeds were used. The windchill indices for these stations were established for the identical period as the Weather Bureau 5-year summaries, and the regression correlation established with the windchill averages obtained

TABLE VII
FORT CHURCHILL TEMPERATURE, WINDSPEED, WINDCHILL INDEX
AND WINDCHILL AVERAGES, 1948-1957

	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	Avg.
Temp. (°F)	-14.0	-14.4	-33.6	-18.4	-19.5	-21.2	-25.4	-16.3	-10.7	-23.3	-19.7
Windspeed (mph)	15.8	17.5	13.6	12.5	17.9	14.6	13.9	15.5	13.2	20.5	15.5
Windchill Index	1751	1795	2011	1735	1891	1843	1891	1781	1632	2008	1824
Windchill Average	1704	1768	1974	1702	1805	1697	1832	1729	1553	1962	1773
Deviation	47	27	37	33	86	146	59	52	79	46	51

from the frequency tabulations of hourly observations. The results of this test, involving stations with indices between 500 and 1400 windchill, show a tendency for the arithmetic mean from frequency tabulations to be slightly less than that from the index, but they do increase regularly as the index increases. At the 5 stations below the 700 windchill index, the deviations were all plus, whereas only one of the 8 stations above 800 showed a plus deviation. In the 7 other stations, averages from frequencies were in all cases less than the index.

A further test of this tendency was obtained between indices 355 and 1735 by the use of the 20 stations of the model. For the windchill index in this case, the temperatures were averaged for the period, using the mid-mark of each 5-degree temperature class; the average windspeed was obtained from the adjusted windspeed for each Beaufort class. Since this was the temperature and windspeed used for each bivariate class in establishing the windchill frequencies, it was considered equally accurate for establishing the averages. In this test, 19 of the 20 stations showed an arithmetic mean from the frequencies less than that from the index, again increasing as the windchill index increases. Only at Miami, index 355, was the trend reversed.

A final test was made of 14 Canadian stations with windchill indices between 1000 and 2050. While these data were based on simultaneous recordings, and frequencies were established in the same bivariate classification as for the 20-station model, the number of observations varied greatly from station to station, due to variation in the number of daily observations.

At all of these stations the means of the frequency data were consistently less than the indices.

Below 700 windchill index the means are slightly above the index, but above 700 windchill the means are less and deviations increase as the indices increase. Even at Churchill, where high winds are associated with the colder temperatures, the mean windchill is consistently below the index as indicated in the year-by-year records (See Table VII).

Not only was the mean windchill below the index, but, as indicated in Table VI, the 50th percentiles were consistently less than the index. The 20-station average of the 50th percentiles was 918 windchill units, whereas the average of the indices was 995, a difference of approximately 75 units.

(2) Theoretical and practical windchill limits

There are theoretical upper and lower limits to the windchill at any station within which all windchill frequencies will fall. If the coldest temperature were associated with the strongest wind and the highest temperature with calm, then theoretical limits would be met. For example, at Minneapolis, where January windchill index based on long-term averages of temperature and windspeed is 1270, a windchill less than 186 or greater than 2368 would never be experienced, based on the all-time January high of 58°F with calm or the all-time January low of -31°F with a 40-mph wind. However, calm with the high temperature seems to be a more prevalent condition than maximum windspeed with coldest temperatures. It is almost a truism that calm and cold temperatures are more often associated.

If the wind-temperature relationship given in Climatic Extremes for Military Equipment (17) (i.e., 80-mile wind at 0°F. decreasing 1 mph for each F° decrease in temperature) is accepted for computing maximum windchill, -50°F. with a 30 mph wind or -60°F. and 20 mph wind will give approximately 2600 windchill as the maximum to be expected.

Low elevation station

This 2600 windchill limit held true for the strongest wind in ten years (45 mph) at Verkhoyanch, Siberia (400 ft.), which was associated with -10°F, giving only 1972 windchill. An investigation of all the -75°F and below temperatures at this cold spot showed that in 66 out of 68 occurrences, windspeeds were less than 3 mph and at the other 2 occurrences windspeed did not exceed 7 mph. Thus it would be hard to believe that the -90°F all-time low was associated with a windspeed sufficient to produce a windchill greater than 2600 units. The 3-year worst combination at Little America -50°F with 25 mph windspeed, or 2392, falls short of this maximum. At none of the 15 Alaskan and Canadian Arctic stations studied for this report was this maximum attained, although it was approached.

HIGH ELEVATION STATION

ON THE GREENLAND ICECAP, TWO JANUARY RECORDS WERE AVAILABLE FOR STUDY; MAXIMUM WINDCHILL BETWEEN 2625 AND 2650 WAS RECORDED ONLY ONCE EACH YEAR, ONE OBSERVATION OF -50°F. AND 26 MPH WIND, AND ONE OBSERVATION OF -76°F. AND 12 MPH WIND, RESPECTIVELY. IT IS NOTED THAT THE WIND IS A LITTLE HIGH FOR THE RULE, BUT THE STATIONS WERE LOCATED AT A HIGH ELEVATION, WHERE AIR IS LESS DENSE. HIGHER WINDCHILL VALUES WERE REPORTED FROM THE SOUTH POLE STATION, WHERE TEMPERATURES OF -50 TO -90°F WERE ASSOCIATED WITH 20- TO 30-MPH WINDS. MR. PAUL DALRYMPLE (QMC METEOROLOGIST STATIONED AT THE SOUTH POLE) HAS REPORTED TEMPERATURE AND WINDSPEED AVERAGES OF -67.4°F. AND 19.6 MPH, RESPECTIVELY FOR JULY 1958; THIS PRODUCES A MONTHLY WINDCHILL INDEX OF 2755. THE EXTREME LOW TEMPERATURE FOR THAT MONTH WAS -96.0°F., WHICH WAS ASSOCIATED WITH A 19-KNOT WIND (21.9 MPH) AND PRODUCED A 3322 WINDCHILL. IT HAS NOT BEEN ESTABLISHED AT THE PRESENT WRITING IF OTHER COMBINATIONS OF SIMULTANEOUS RECORDINGS GAVE A GREATER EXTREME VALUE. THIS AGAIN WAS AT A HIGH ELEVATION.

THUS IT CAN BE SEEN THAT WHILE EXTREME MAXIMUM LIMITS OF WINDCHILL BASED ON MAXIMUM WINDSPEEDS AT LOW TEMPERATURES ARE POSSIBLE, THE CHANCE OF THEIR OCCURRING SIMULTANEOUSLY AT LOW ELEVATIONS IS HIGHLY IMPROBABLE, BUT SUCH A COMBINATION DOES GIVE THE UPPER LIMIT OF EXPECTANCY. THE LOWER LIMIT, PRODUCED BY THE ASSOCIATION OF HIGHEST TEMPERATURE WITH A CALM CONDITION, IS A MUCH MORE PREVALENT PHENOMENON AND ACCOUNTS FOR THE TENDENCY FOR THE STATION'S THEORETICAL MINIMUM WINDCHILL TO OCCUR, REGARDLESS OF THE INDEX OR AREA FROM WHICH DRAWN. THUS THERE ARE PRACTICAL LIMITS WITHIN WHICH ALL FREQUENCY WINDCHILL DATA WILL FALL.

(3) HISTOGRAMS OF WINDCHILL FREQUENCY DISTRIBUTION AT MODEL STATIONS

ALTHOUGH WINDCHILL DISTRIBUTION MAY APPROACH A BELL CURVE, THIS IS NOT ALWAYS THE CASE; AND SOME SHOW MARKED SKEWNESS AS SHOWN BY THE DISTRIBUTION HISTOGRAMS (FIG. 3) OF THE INDIVIDUAL STATIONS USED TO MAKE UP THE MODEL. WINDCHILL DISTRIBUTION IS DETERMINED BY THE MANNER IN WHICH THE TWO ELEMENTS ARE ASSOCIATED AND MAY OR MAY NOT FOLLOW THE PATTERN OF EITHER THE TEMPERATURE OR WIND DISTRIBUTION PATTERNS. TO ILLUSTRATE, A FEW STATIONS WILL BE ANALYZED.

AT MIAMI (STATION 1), THE MEAN TEMPERATURE IS 67.9°F. AND MEAN WINDSPEED IS 10.1 MPH WITH A CORRESPONDING TEMPERATURE FACTOR OF 23.5 AND WIND FACTOR OF 15.085 PRODUCING A 355 WINDCHILL INDEX FOR THE PERIOD FOR WHICH THE FREQUENCY TABULATIONS ARE AVAILABLE. THE JANUARY TEMPERATURE RANGE FROM 30 TO 89°F. IS SKEWED TOWARD THE LOWER TEMPERATURE VALUE WITH THE MODE IN THE 70 TO 74°F. CLASS INTERVAL WHEREAS THE MEAN FALLS IN THE 65 TO 69°F. CLASS INTERVAL. HIGHER TEMPERATURES ARE ASSOCIATED WITH HIGHER WINDSPEED VALUES; THIS TENDS TO MINIMIZE WINDCHILL VALUES AND PRODUCES A WINDCHILL CURVE SKEWED TOWARD

HIGHER WINDCHILL VALUE. THE WINDCHILL RANGE IS BETWEEN 65 AND 975 WITH THE 50TH PERCENTILE AT 320, 35 WINDCHILL UNITS BELOW THE INDEX OF 355.

AT SAN DIEGO (STATION 3), ALL TEMPERATURES FALL WITHIN THE SAME 30 TO 89F° RANGE AS DID THOSE OF MIAMI. THE SAN DIEGO AVERAGE TEMPERATURE, 53.7°F., IS 24.2F° LOWER, INCREASING THE TEMPERATURE FACTOR OF THE FORMULA TO 37.7. THE AVERAGE WINDSPEED OF 6.2 MPH IS, HOWEVER, LOWER THAN AT MIAMI, DECREASING THE WINDCHILL FACTOR TO 13.496. WHEN THESE TWO FACTORS ARE COMBINED, THE RESULTANT WINDCHILL INDEX IS 510. BOTH THE TEMPERATURE AND WIND DISTRIBUTIONS TEND TO CLUSTER CLOSE TO THEIR RESPECTIVE MEANS. SIXTY PERCENT OF ALL TEMPERATURES FALL WITHIN 50 TO 59°F. AND 89 PERCENT OF ALL WINDSPEEDS WITHIN THE 1-3, 4-7, AND 8-12 CLASSES. THIS COMBINATION GAVE A RANGE FROM 35 TO 900 WINDCHILL UNITS, MUCH LIKE MIAMI BUT HAVING QUITE A DIFFERENT DISTRIBUTION PATTERN. AT SAN DIEGO 47 PERCENT OF ALL WINDCHILL UNITS WERE IN THE 450 TO 549 CLASS CLOSE TO THE 510 WINDCHILL INDEX.

ST. PAUL ISLAND (STATION 13), HAS NO GREATER TEMPERATURE RANGE THAN EITHER MIAMI OR SAN DIEGO BUT IS 40 DEGREES LOWER ON THE TEMPERATURE SCALE WITH RANGE BETWEEN -5 AND 44°F. THE AVERAGE TEMPERATURE IS 27.4°F. THUS IT HAS A TEMPERATURE FACTOR OF 64. THIS IS A VERY WINDY STATION WITH AN AVERAGE WINDSPEED OF 18 MPH OR A WIND FACTOR OF 17.08. COMBINING THE TEMPERATURE AND WIND FACTORS, A 1095 WINDCHILL INDEX IS OBTAINED. THE TEMPERATURE DISTRIBUTION AT THIS STATION IS VERY STRANGE. THE MODAL CLASS 30 TO 34°F. HAS 47.9% OF ALL THE RECORDED TEMPERATURES. HIGHER-THAN AVERAGE WINDSPEEDS ARE ASSOCIATED WITH THESE HIGHER-THAN-AVERAGE TEMPERATURES. WINDCHILL DISTRIBUTION TENDS TO BE NORMAL WITH HIGH CONCENTRATION BETWEEN 850 AND 1150 WINDCHILL UNITS, WITH THE 50TH PERCENTILE AT 1040 EVEN THOUGH THE RANGE IS FROM 360 TO 1665.

CHURCHILL (STATION 20) WITH AVERAGE TEMPERATURE OF -13.6°F. AND WINDSPEED OF 15.27 MPH, HAS CORRESPONDING TEMPERATURE AND WIND FACTORS OF 105 AND 16.94, RESPECTIVELY, OR A WINDCHILL INDEX OF 1735 FOR THE PERIOD OF THE FREQUENCY TABULATIONS. THE TEMPERATURE RANGE AT CHURCHILL IS WIDER, 95F° (-60° TO 35°). THE TEMPERATURE DISTRIBUTION HAS BOTH MEAN AND MODE WITHIN THE SAME CLASS INTERVAL (-11 TO -15°F.). SINCE THIS CLASS INTERVAL ACCOUNTS FOR ONLY 13.3% OF ALL THE OBSERVATIONS, AND EACH OF TWO CLASS INTERVALS ON EITHER SIDE OF THE MEAN HAVE ALMOST AS MANY OF THE OBSERVATIONS, THE DISTRIBUTION OF TEMPERATURE THUS MAKES A VERY FLAT CURVE. THIS STATION ALSO HAS A WIDE WINDCHILL RANGE - 489 TO 2400. HOWEVER, HIGH WINDSPEEDS ARE ASSOCIATED WITH LOW TEMPERATURES AT THIS PARTICULAR STATION IN CONTRAST TO THE SITUATION AT MIAMI. THE WINDCHILL CURVE SHOWS A DECIDED SKEWNESS TOWARD LOW WINDCHILL VALUES. WINDCHILL DISTRIBUTION SHOWS TWO MODES, ONE OF 1650 TO 1749 AND ANOTHER OF 1850 TO 1949.

THUS, SIMULTANEOUS OBSERVATIONS OF THE TWO ELEMENTS WILL PRODUCE A MORE SENSITIVE MEASURE OF COOLING POWER THAN EITHER WIND OR TEMPERATURE USED SEPARATELY. WHILE IT MIGHT APPEAR ON CASUAL OBSERVATION THAT HIGH

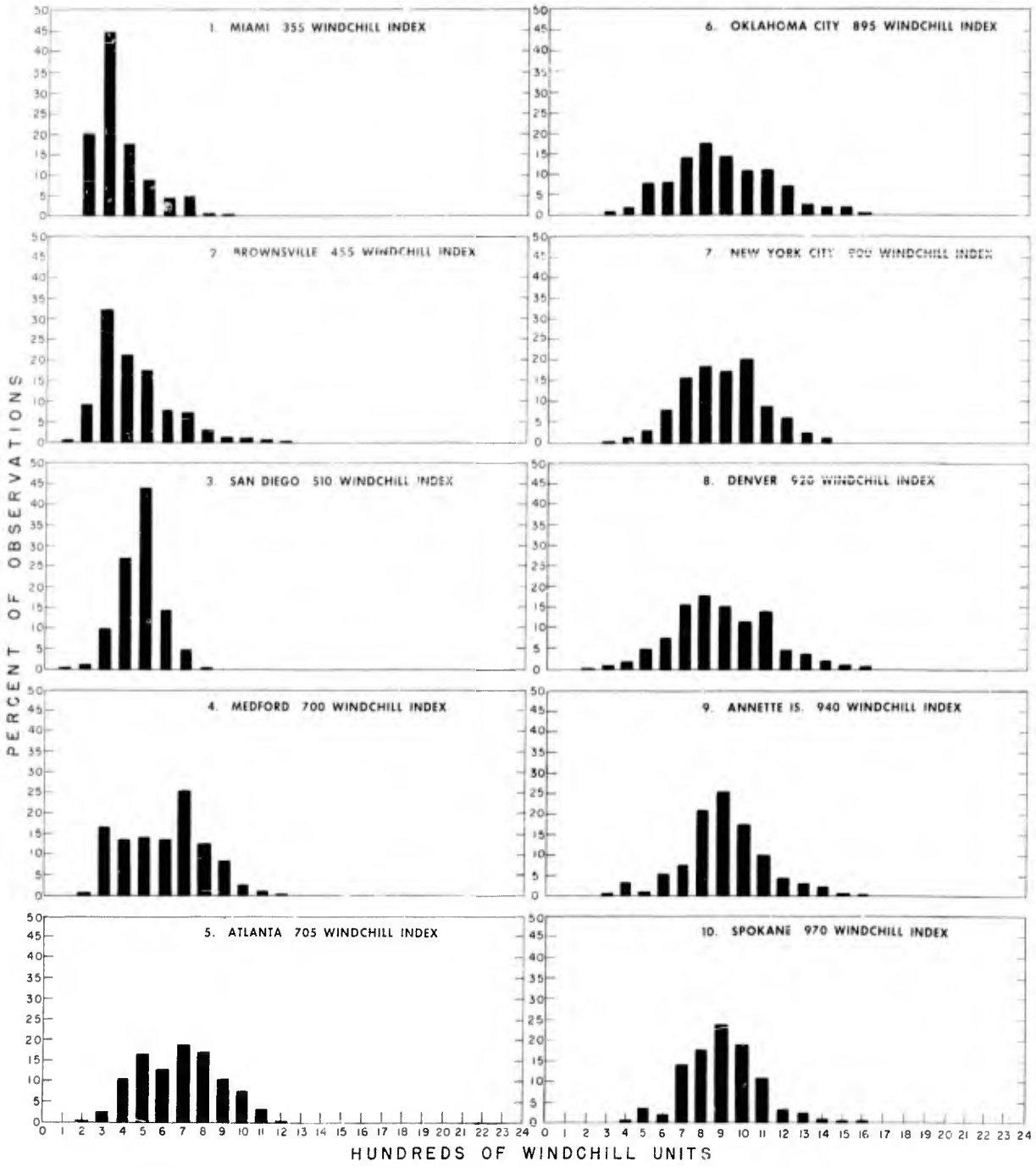
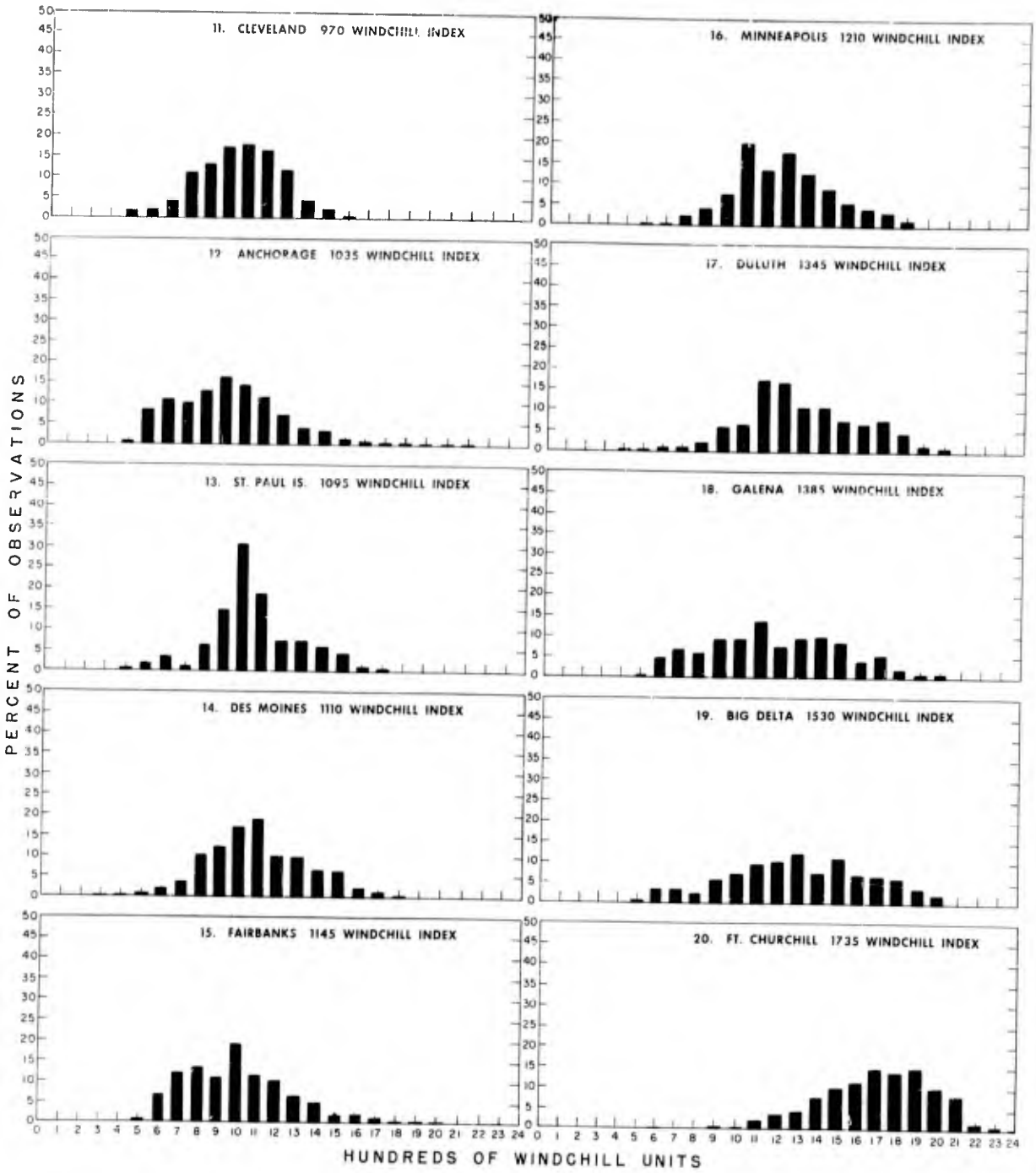


FIGURE 3: HISTOGRAMS OF WINDCHILL DISTRIBUTION



FOR THE TWENTY STATIONS IN THE MODEL

AVERAGE WINDSPEEDS WOULD PRODUCE AN ABNORMAL WINDCHILL DISTRIBUTION, THIS DOES NOT SEEM TO BE THE CASE. THE INFLUENCE OF HIGH AVERAGE WINDSPEED HAS BEEN LARGELY DISCOUNTED WHEN THE INDEX WAS DETERMINED FROM THE LONG-TERM AVERAGES. IT IS THE DISTRIBUTION OF THE SIMULTANEOUS OCCURRENCES OF TEMPERATURE AND WINDSPEED WHICH DETERMINES THE SHAPE OF THE WINDCHILL CURVES (FIG. 3).

(4) THE COMPOSITE WINDCHILL PROBABILITY CHART

FROM THE FREQUENCY DATA FOR THE 20 STATIONS (TABLE VI) USED TO ESTABLISH THE PREDICTION CHART, A SET OF BAR GRAPHS (FIG. 4) WAS CONSTRUCTED FOR EACH WINDCHILL INDEX FROM 300 TO 2000 TO SHOW THE RANGE AND PROBABLE DISTRIBUTION OF ACTUAL WINDCHILL. THESE BAR GRAPHS ARE NOT ACTUAL DISTRIBUTIONS AT AN INDIVIDUAL STATION AS IN THE CASE OF THE HISTOGRAM CHARTS (FIG. 3), BUT ARE A COMPOSITE OF PERCENTILE DISTRIBUTION OF THE 20 STATIONS. IT WILL BE NOTED THAT THE WINDCHILL RANGE INCREASES AS THE INDEX INCREASES, BUT AT A DECREASING RATE; WHILE THE RANGE IS 2.66 TIMES THE INDEX AT 300 WINDCHILL, IT HAS DIMINISHED TO A RATIO OF 1 TO 1 AT THE 2000 WINDCHILL INDEX. SINCE THE 50TH PERCENTILE IS REACHED AT 290 ON THE ACTUAL WINDCHILL SCALE FOR A STATION WITH 300 INDEX, IT IS APPARENT THAT THE DISTRIBUTION CURVE IS SKEWED TO THE RIGHT, SINCE THE REMAINING 50% OF THE DISTRIBUTION IS SPREAD OUT OVER 510 WINDCHILL UNITS. AT THE 2000 WINDCHILL INDEX THE OPPOSITE TENDENCY IS OBSERVED, WITH SKEWNESS TO THE LEFT. FIFTY PERCENT OF THE DISTRIBUTION IS IN THE LOWER 1200 WINDCHILL UNITS BETWEEN 580 AND 1780, AND THE REMAINING 50% CONCENTRATED IN A RANGE OF 800 UNITS BETWEEN 1780 AND 2580. SINCE THE RANGE IS GREATER FOR THE 2000 WINDCHILL INDEX, THE CURVE IS MUCH FLATTER. ONLY BETWEEN THE 1200 TO 1600 WINDCHILL INDICES DOES THE DISTRIBUTION APPROACH SYMMETRY IN THIS COMPOSITE PREDICTION CHART, ALTHOUGH MANY OF THE INDIVIDUAL STATIONS MAY APPROACH A BELL CURVE (FIG. 3).

THE ASSOCIATION OF SOME CALM WITH WARMER TEMPERATURES TENDS TO KEEP THE GRADATION OF THE LOWER WINDCHILLS AT A MINIMUM AS THE INDICES INCREASE. IT IS THE HIGH WINDS USHERING POLAR AIR INTO A WARM REGIME WHICH ACCOUNT FOR THE LONG TAILS TO THE RIGHT IN THE DISTRIBUTION OF THE LOWER INDICES. SINCE WINDS TEND TO DECREASE WITH VERY COLD TEMPERATURES, THE HIGHER INDICES ARE FORESHORTENED ON THE RIGHT. THE OCCASIONAL WARM SPELLS ASSOCIATED WITH LOW WINDSPEEDS ARE REFLECTED IN LONG TAILS TO THE LEFT.

4. THE WINDCHILL PREDICTION CHART (FIG. 5)

THE PREDICTION CHART IS A COMBINATION OF THE SIPLE WINDCHILL NOMOGRAM (USED IN THIS CASE TO ESTABLISH THE INDEX FROM THE LONG-TERM AVERAGES OF TEMPERATURE AND WINDSPEED) AND THE SET OF WINDCHILL DISTRIBUTION CURVES, DEVELOPED BY CURVILINEAR METHOD, EZEKIEL, 1941(6) FROM THE ACTUAL FREQUENCIES (TABLE VI) OF THE 20-STATION MODEL USED AS A PREDICTOR. THE DISTRIBUTION CURVES ARE SUPERIMPOSED ON ARITHMETIC PROBABILITY PAPER WITH SCALES

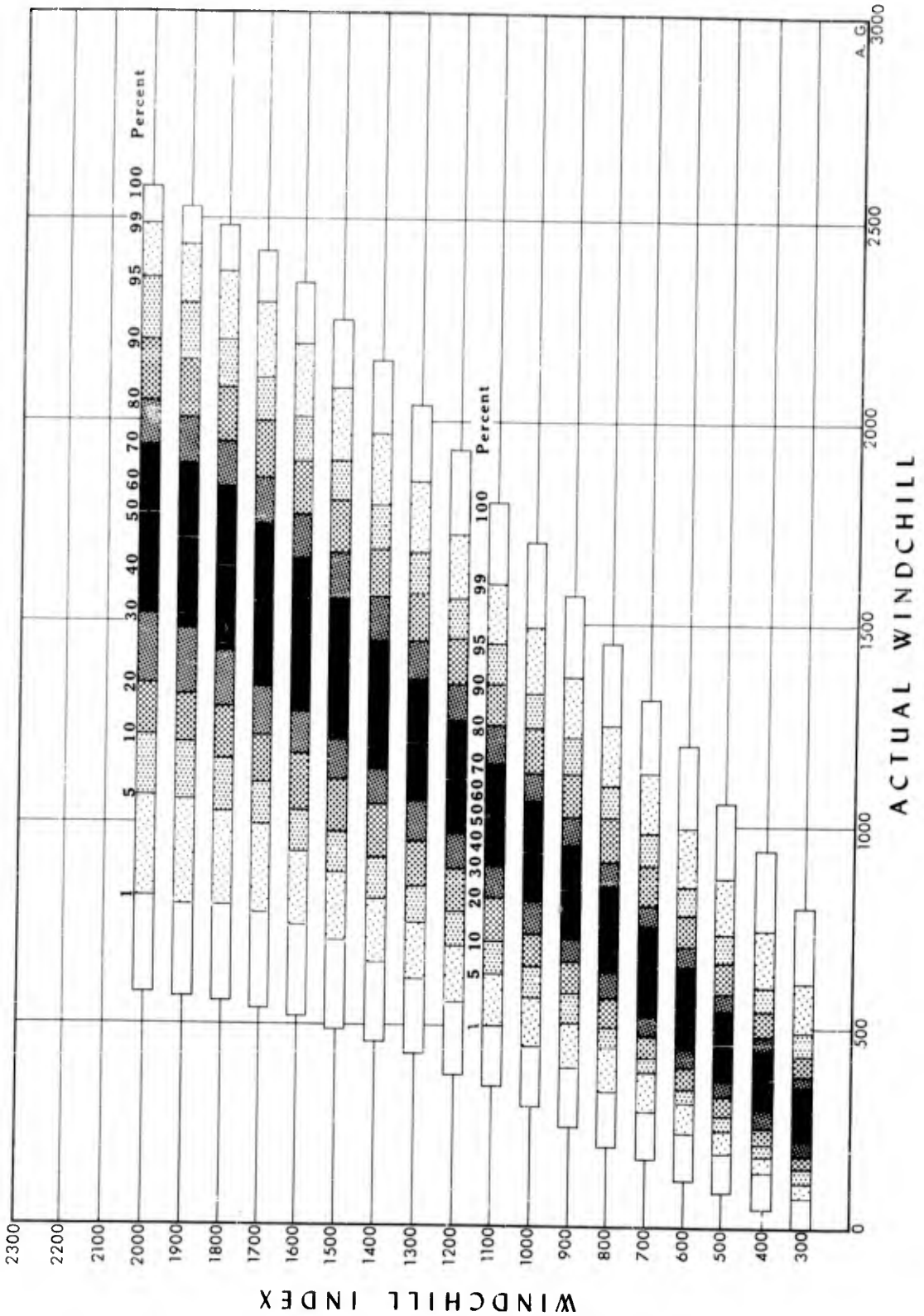


FIGURE 4: PROBABLE PERCENTILE DISTRIBUTION OF ACTUAL WINDCHILL (KG CALS/M^2/HR)

WINDCHILL PREDICTION CHART

EXPLANATION ON USE OF CHART

BY A SIMPLE TECHNIQUE, IT IS POSSIBLE TO ESTIMATE THE PROBABILITY OF A SPECIFIED LEVEL OF WINDCHILL. DATA REQUIRED (MEAN MONTHLY AIR TEMPERATURE AND WINDSPEED) ARE ENTERED IN THE SIPLE WINDCHILL NOMOGRAM AT THE LEFT AND A WINDCHILL INDEX OBTAINED. THIS INDEX IS TRANSFERRED TO THE PREDICTION CHART AT THE RIGHT AND FOLLOWED TO THE PREDETERMINED LEVEL DESIRED (READ ON ACTUAL WINDCHILL SCALE AT THE EXTREME RIGHT). PERCENTAGE FREQUENCY CAN BE READ ON THE PROBABILITY SCALE AT EITHER TOP OR BOTTOM OF THE PREDICITION CHART.

EXAMPLE: AT FORT CHURCHILL, JANUARY MEAN TEMPERATURE (-18°F) AND WINDSPEED (14.9 MPH) ENTERED IN THE NOMOGRAPH AT THE LEFT GIVE AN 1,800 WINDCHILL INDEX. THIS 1,800 INDEX INTERSECTS THE 1,400 ACTUAL WINDCHILL (CONDITION AT WHICH EXPOSED FLESH FREEZES) AT 72 PERCENT ON THE UPPER SCALE OR 28 PERCENT ON THE LOWER SCALE, INDICATING THAT DANGER OF FREEZING IS A PROBABILITY 72 PERCENT OF THE TIME AT CHURCHILL DURING JANUARY SAFETY FROM FREEZING IS A PROBABILITY 28 PERCENT OF THE TIME. THE POSSIBILITY OF THE SITUATION BECOMING DANGEROUS FOR TRAVEL OR LIVING IN TEMPORARY SHELTERS (2,000 ACTUAL WINDCHILL) IS A PROBABILITY 16 PERCENT OF THE TIME.

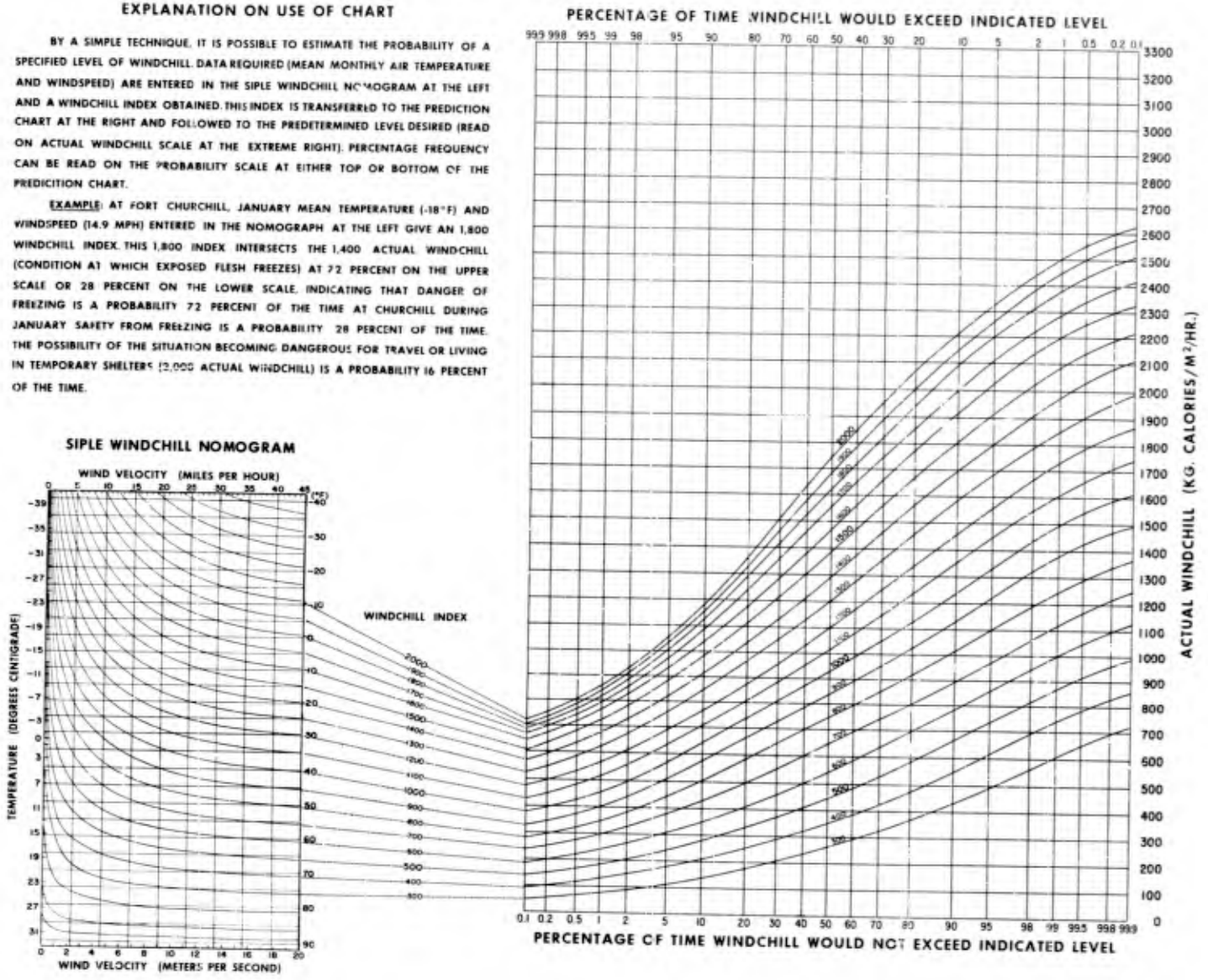


FIGURE 5: WINDCHILL PREDICTION CHART

AT BOTH TOP AND BOTTOM FOR READING THE PROBABILITY PREDICTIONS, "GREATER THAN" AT THE TOP, AND "LESS THAN" AT THE BOTTOM. HORIZONTAL LINES EVENLY SPACED ARE USED TO DENOTE ACTUAL WINDCHILL VALUES IN KG CAL/M^2/HR AND ARE INDICATED ON THE SCALE AT THE RIGHTHAND SIDE OF THE PREDICTOR CHART.

TO MAKE A PREDICTION FROM LONG-TERM MEANS, TEMPERATURE AND WIND ARE FED INTO THE SIPLE NOMOGRAM ON THEIR RESPECTIVE SCALES. THE INTERCEPT OF THE TEMPERATURE AND WIND SCALES IS THEN PICKED UP ON THE CURVED WINDCHILL SCALE, WHICH IS NOW DESIGNATED THE "WINDCHILL INDEX." THE WINDCHILL INDEX IS THEN FOLLOWED DOWNWARD TO THE RIGHT TO CONNECT WITH THE CORRESPONDING WINDCHILL DISTRIBUTION CURVE IN THE PREDICTOR BOX. FOR EXAMPLE: IF A STATION WITH AVERAGE TEMPERATURE OF 45°F. AND 10 MPH WIND IS SELECTED, IT CAN BE DETERMINED ON THE SIPLE NOMOGRAM TO HAVE A 700 WINDCHILL INDEX. WHEN THE 700 WINDCHILL INDEX IS FOLLOWED ONTO THE DISTRIBUTION CURVE IN THE PREDICTOR BOX IT CROSSES THE 700 ACTUAL WINDCHILL (HORIZONTAL LINE) ON THE 40TH PERCENTILE READ ON THE UPPER SCALE. IT CAN BE SAID THAT ANY PLACE WITH A 700 WINDCHILL INDEX WILL PROBABLY EXPERIENCE ACTUAL WINDCHILL VALUES GREATER THAN 700 APPROXIMATELY 40% OF THE TIME. FURTHERMORE, IT CAN BE PREDICTED THAT ALL STATIONS WHERE THE LONG-TERM AVERAGES PRODUCE A 700 WINDCHILL INDEX ON THE SIPLE NOMOGRAM, REGARDLESS OF THE COMBINATION OF JANUARY AVERAGE TEMPERATURES AND WINDSPEEDS PRODUCING THE 700 INDEX (DETERMINED BY INTERCEPTS OF TEMPERATURE AND WIND ALONG THE 700 INDEX), WILL SELDOM EXPERIENCE ACTUAL WINDCHILL LESS THAN 250 OR GREATER THAN 1200 UNITS DURING THE MONTH OF JANUARY.

AS A FURTHER EXAMPLE: IF ONE WISHES TO KNOW THE SEVERITY OF CONDITIONS AT DULUTH, MINNESOTA, THE LONG-TERM AVERAGES OF TEMPERATURE AND WINDSPEED ARE ASCERTAINED. THEY ARE FOUND TO BE 10.3 AND 12.3, RESPECTIVELY. IN THIS CASE, THE 10.3 POSITION ON THE FAHRENHEIT TEMPERATURE SCALE WOULD NEED TO BE ESTIMATED ON THE RIGHTHAND SIDE OF THE SIPLE NOMOGRAM AS WELL AS THE 12.3 ON THE MPH SCALE AT THE TOP OF THE NOMOGRAM. FROM THE POINT WHERE THESE TWO ESTIMATED LINES INTERSECT, THE WINDCHILL CURVE (APPROXIMATELY 1300 INDEX) IS FOLLOWED INTO THE PREDICTOR BOX (RIGHT-HAND SECTION OF THE PREDICTION CHART). IF IT IS ASSUMED THAT AN AVERAGE PERSON DRESSED IN WINTER CLOTHING IS SAFE BELOW 1400 WINDCHILL, IT CAN BE ESTIMATED THAT SAFE CONDITIONS PREVAIL 78% OF THE TIME, IN THIS CASE READ ON THE LOWER SCALE OF THE PREDICTION BOX. IF IT IS CONSIDERED DANGEROUS AT WINDCHILL GREATER THAN 1900, IT CAN BE PREDICTED THAT DANGEROUS CONDITIONS WILL BE ENCOUNTERED ONLY 1% OF THE TIME, READ AT TOP OF THE PREDICTION BOX. ALL INTERMEDIATE CONDITIONS WOULD BE CONSIDERED MARGINAL (1400 TO 1900 WINDCHILL) AND WOULD BE EXPECTED APPROXIMATELY 20% OF THE TIME.

IF ONE HAS A PREFERENCE FOR USING TABLES RATHER THAN A CHART, THE INFORMATION NECESSARY FOR APPLICATION OF THE FORMULA AND ASSESSING PERCENTILE FREQUENCIES IS GIVEN IN TABLES IX AND X, APPENDIX.

From the long-term temperature and windspeed averages, it would be possible by a series of windchill frequency predictions to establish the calculated risk involved in any number of field operations where the exposure of human beings is a consideration. For instance, a piece of equipment might be operated under conditions of very high windchill, except for the fact that it is to be operated by a soldier who is too cold or too encumbered by his (cold-weather) clothing to perform the necessary operation. The percentage of time those conditions existed would be a part of the calculated risk involved in any maneuver.

5. Performance Testing

Since a prediction is only as good as the reliance which can be placed on it, a series of tests were conducted to evaluate the accuracy of the prediction chart. Detailed information on deviations from predictions for each station are shown for each check point in Table XI, Appendix. In addition, a summary of errors is given for each station. In contrast to this table, which summarizes errors on a station or windchill index basis, in Table XII, Appendix, the percentile is the focal point. It is thus possible to check any station given in Table XI, Appendix, to see at which percentiles deviations are greater or less than average for that station. By use of Table XII, Appendix, it is possible to tell if the station is normal in relation to other stations at any given percentile.

A summarization of averages at all stations used in the model and in the various tests is given in Table VIII of the text, which can be used for an overall picture. For detail see the Appendix tables.

A. Test of the model (Test I)

Test I was made with the actual frequency data from the 20-station model. Deviations of the actual frequency from the prediction were ascertained for each station at 15 percentile check points: .01% and 99.99%, the 1st and 99th, the 5th and 95th, and all intervening 10th percentiles. Thus the model was checked at 300 intersections and found to have an average deviation of 52 windchill units, with range from 0 to 240, but with 63% of the deviations less than the 52 windchill average as shown in the cumulative frequency error chart (Fig. 6). The number of plus errors was greater than the number of minus errors, but the average magnitude of plus and minus errors was essentially the same. As with most predictive methods, better results were obtained through the mid-percentiles, with errors greater toward either extreme. However, the .01 percentile windchill was predicted with accuracy greater than the average and equal to the best of the mid-percentiles. At 99% and 99.99% and between the 5% and 40% percentiles the errors were greater than the average. The "least possible" (read on .01% percentile) and 60th percentile predictions were

TABLE VIII
SUMMARY OF AVERAGES OF 3 TESTS*

Windchill Index Range	Average Wind	Average Temp.	Average Windchill	Check Points	Average Errors	Average "+" Ers	Average "-" Ers	Number "+" Ers	No Errors	Number "-" Ers
355-1735 Model (Test I)	10.748	24.67	994.25	300	52.51	51.25	52.57	164	12	124
580-2075 Test II	10.257	13.14	1173.08	300	90.83	74.68	111.45	144	8	148
460-1235 Test III	11.292	34.64	810.35	210	48.26	55.69	37.76	144	10	56
460-2075 Tests II & III	10.316	13.04	1153.83	510	73.30	65.19	91.22	288	18	204
355-2075 Combined Tests	10.476	17.41	1106.85	810	65.61	60.13	79.19	452	30	328

*For fuller detail see Tables XI and XII, Appendix

of equal accuracy and in greatest conformity with the predictions. At "least possible," the deviations ranged between 0 and 85 with an average of 36.75 windchill units. The range of error at the "most possible" (99.99th percentile) was from 0 to 190 windchill units with average of 76. Since predictions were good in the more critical zone, it was decided to leave the predictor chart as constructed and test by other randomly-chosen stations.

B. Further Testing

The 34 stations chosen for further testing were divided into two groups according to the source material. Twenty stations were from the Asheville Summaries (8), designated Test Group II. These stations gave limited coverage in the United States, but were a good sample of northern stations. The indices of only four stations were below 1000, while the remaining stations ranged from 1000 to 2075 windchill. The other 14 stations, designated Test Group III, all from the United States, were selected from the Weather Bureau Summaries (21). The range of indices for Test Group III was from 460 to 1235 windchill.

(1) Based on Asheville Summaries (Test II)

The results of Test II did not show as close correlation with predictions as Test I (based on the 20-station model), but showed the same general pattern with best conformity in the mid-percentiles. Again, the .01% windchill was predicted as well as the mid-range, and better than the 99.99%. Actual windchill values less than the predicted were the usual pattern at the far north stations between the 1st and the 30th

PERCENTILE, WHERE DEVIATIONS WERE AS MUCH AS 300 OR 400 UNITS IN SOME CASES. SINCE HALF OF THE STATIONS OF THIS GROUP WERE FROM THE FAR NORTH, AND POSSESSED THIS TENDENCY, THE AVERAGE ERROR HAS BEEN INCREASED TO 90 WINDCHILL UNITS FOR THE GROUP WITH MINUS DEVIATIONS 20 POINTS ABOVE THE AVERAGE. THIS IS AN ACCENTUATION OF THE BIAS IN THE PREDICTION MODEL, AND IS LARGELY ELIMINATED BEYOND THE 30TH PERCENTILE. BETWEEN THE 30TH AND 90TH PERCENTILES THE PREDICTIONS ARE VERY GOOD, WITH THE PATTERN CHANGING TO A PLUS DEVIATION EQUAL TO ABOUT HALF THE AVERAGE.

(2) Based on Weather Bureau summaries (Test III)

TEST III PRODUCED AN AVERAGE DEVIATION LESS THAN THAT OF THE ORIGINAL 20 STATIONS; BUT, SINCE THE TEST IS OF THE LOW AND MID-RANGE WINDCHILL INDICES, THIS IS UNDERSTANDABLE. HOWEVER, AT MORE OF THE CHECK POINTS THE ACTUAL WINDCHILL EXCEEDED THE PREDICTION. NOT ONLY DID PLUS DEVIATIONS OUTNUMBER THE MINUS DEVIATIONS, BUT THE MAGNITUDE OF THE PLUS DEVIATIONS WAS GREATER ON THE AVERAGE BY 20 WINDCHILL UNITS. ALSO, AT 14 OF THE 15 CHECK POINTS, THE PLUS DEVIATION WAS ALWAYS GREATER THAN THE MINUS DEVIATION; ONLY AT THE 99.99 PERCENTILE WAS THIS TENDENCY REVERSED. THIS PHENOMENON WAS IN CONTRAST TO TESTS I AND II AND DESERVES AN EXPLANTION. THE KEY TO THE SOLUTION IS UNDOUBTEDLY IN THE COARSER WINDSPEED BREAKDOWN OF THE SOURCE DATA AND CAN BE ILLUSTRATED WITH THE EXAMPLE OF THE LEAST POSSIBLE (.01%) WINDCHILL EXPECTED. IT WILL BE NOTED THAT OF 14 STATIONS TESTED (TABLE XI, APPENDIX), 12 SHOW A PLUS DEVIATION, OF WHICH HALF ARE GREATER THAN THE AVERAGE FOR THE TEST BUT ALSO GREATER THAN THE AVERAGE AT EITHER TEST I OR TEST II. THE PREDICTIONS WERE MADE ON THE SUPPOSITION THAT EACH STATION WOULD SHOW AT LEAST ONE INSTANCE OF 0 MPH WITH THE HIGHEST TEMPERATURE. HOWEVER, WHEN WINDCHILL FOR THE BIVARIATE BLOCK WAS CALCULATED IT WAS AT AN AVERAGE WINDSPEED AND TEMPERATURE FOR THE BLOCK, AND WHILE THE WIND AVERAGE MIGHT BE VERY SMALL, IT WAS ALWAYS A POSITIVE AMOUNT. THE COARSER WIND BREAKDOWN WOULD TEND TO GIVE A HIGHER AVERAGE WIND ASSOCIATED WITH EACH OF THE 5-DEGREE TEMPERATURE BREAKDOWNS, WITH CONSEQUENT HIGHER WINDCHILL FACTOR, AND RESULTS IN A SLIGHTLY HIGHER WINDCHILL VALUE.

c. Summary of combined tests

CUMULATIVE FREQUENCY DISTRIBUTION OF MAGNITUDE OF ERRORS IS DEPICTED FOR EACH OF THE THREE TESTS IN FIGURE 6. THE ERRORS HAVE BEEN SEPARATED IN PLUS AND MINUS COMPONENTS AND ARE SHOWN FOR THE THREE TESTS IN FIGURE 7. AVERAGES OF TEMPERATURE AND WINDSPEED AND WINDCHILL ARE GIVEN IN TABLE IX, APPENDIX, AS WELL AS THE ERRORS AT EACH CHECK POINT. THESE ERRORS ARE SUMMARIZED INTO: "AVERAGE ERROR," "AVERAGE PLUS ERROR" AND "AVERAGE MINUS ERROR," AND INCLUDED IN THE TABLE. THUS IT IS POSSIBLE TO ASCERTAIN IF A PARTICULAR STATION IS ALWAYS ABOVE OR BELOW THE AVERAGE FOR THE TEST, OR WHERE IN THE DISTRIBUTION THE ERRORS OCCUR. GENERAL TRENDS CAN BE ESTABLISHED. FOR INSTANCE:

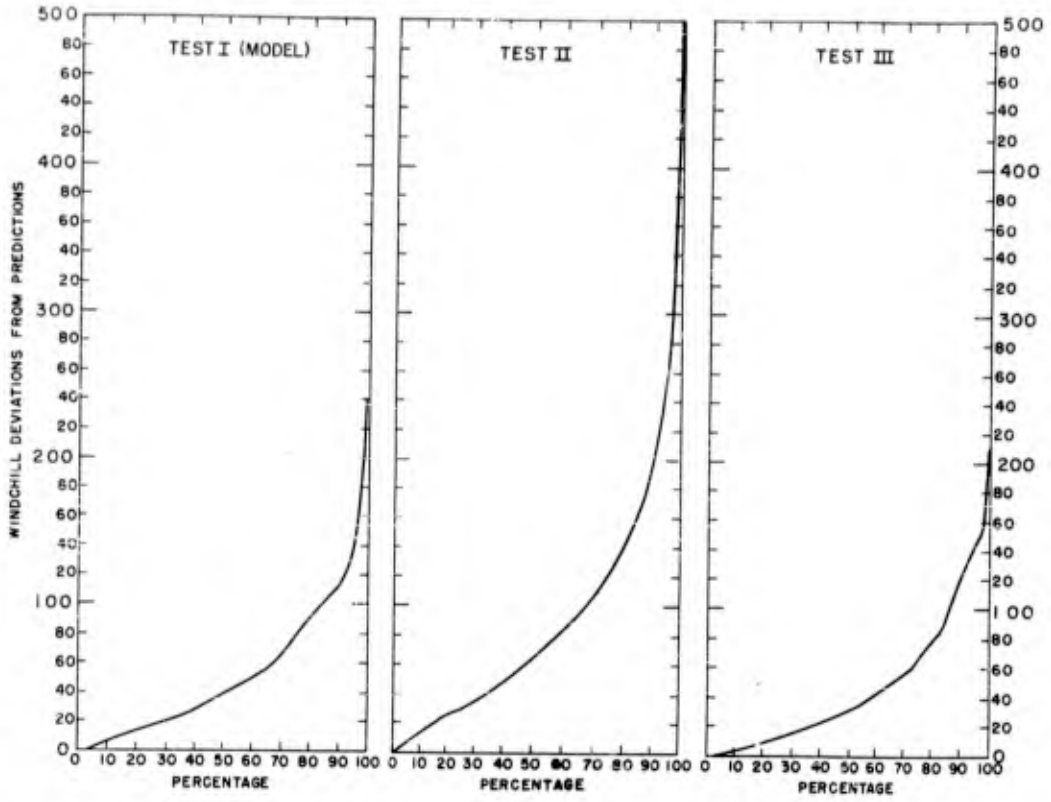


FIGURE 6: CUMULATIVE PERCENTAGE DISTRIBUTION OF PREDICTION ERRORS

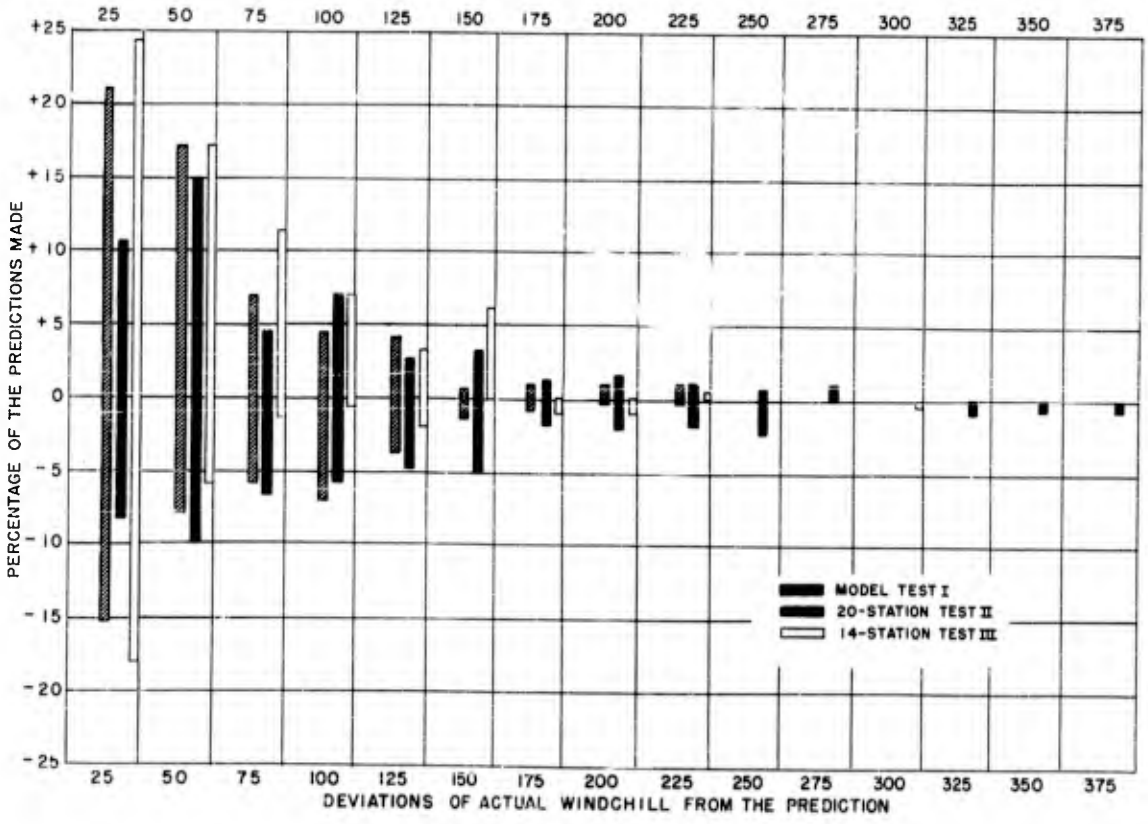


FIGURE 7: CHART OF MAGNITUDE OF PLUS AND MINUS ERRORS

(1) AVERAGE ERROR INCREASES AS THE WINDCHILL INDEX INCREASES

AVERAGE ERROR INCREASES AT A RATE OF TEN UNITS FOR EACH 100 WINDCHILL INCREASE IN THE INDEX ABOVE 800 WINDCHILL. BELOW 800 WINDCHILL, THE RANGE OF AVERAGE ERROR IS FROM 30 TO 100, BUT NO TREND IS APPARENT.

(2) ERRORS ARE CONCENTRATED WHERE EFFECT IS AT A MINIMUM

ERRORS ARE CONCENTRATED AT POINTS WHERE THEIR EFFECTS ARE MINIMIZED OR MAY EVEN BE AN ADVANTAGE; THAT IS, ACTUAL WINDCHILL IS LESS THAN PREDICTED AT SLIGHTLY OVER HALF OF THE STATIONS (TABLE XI, APPENDIX) AT THE 99.99% WINDCHILL CHECK POINT. FURTHER, THE AVERAGE PLUS ERROR IS 15 UNITS LESS THAN THE AVERAGE MINUS ERROR. THE AVERAGE MINUS ERRORS EXCEED AVERAGE PLUS ERRORS AT THE 90TH, 95TH, 99TH PERCENTILES AS WELL. MENTION HAS ALREADY BEEN MADE OF THE MINUS ERRORS IN THE LOWER PERCENTILES AT SEVERAL OF THE NORTHERN STATIONS. AGAIN, THIS CANNOT RESULT IN SERIOUS CONSEQUENCES. WINDCHILL GREATER THAN PREDICTED IS CONCENTRATED AT THE .01 PERCENTILE, AGAIN WHERE IT IS OF INSIGNIFICANCE. OF GREATER SIGNIFICANCE ARE THE WINDCHILL VALUES GREATER THAN PREDICTED AT THE HIGHER PERCENTILES, AND THERE ARE SOME OF THEM.

(3) ANALYSIS OF TYPES OF ERROR

WHILE ANALYSIS OF THE REASON FOR PARTICULAR TYPES OF ERRORS IS NOT THE PRIMARY PURPOSE OF THIS REPORT, IT IS INTERESTING TO NOTE THAT A PARTICULAR TYPE OF WINDCHILL DISTRIBUTION IS ASSOCIATED WITH STATIONS WHICH HAVE SIMILAR LOCATIONAL PATTERNS. FOR INSTANCE, STATIONS LOCATED IN INTER-MOUNTAIN PLATEAUS ALL SHOW THE TENDENCY OF MINUS ERRORS IN THE LOWER PERCENTILES. CALM CONDITIONS WITH WARMER TEMPERATURES ARE OFTEN THE RESULT OF DESCENDING AIR. THIS IS NOTED AT MEDFORD, FAIRBANKS, GALENA, BIG DELTA, WATSON LAKE, BATTLEFORD, AND WHITE HORSE. THIS SAME TENDENCY IS ALSO NOTED AT STATIONS IN THE ARCTIC ARCHEPELAGO, NOT AS WELL PROTECTED FROM ALL SIDES, BUT WHERE SUBSIDENCE OF AIR FROM ALOFT IS RESPONSIBLE FOR CALM OR LOW WIND CONDITIONS AND WARMER TEMPERATURES. WHILE AT SOME OF THESE STATIONS THE AVERAGE WIND IS BELOW THAT OF THE STATIONS AS A WHOLE (10.47 MPH, TABLE VIII), IT IS NOT ALWAYS THE CASE. IF THE WIND DISTRIBUTION IS SKEWED TOWARD THE LOW VALUES, WINDCHILL VALUES WILL BE LOWER THAN PREDICTED EVEN WITH NORMAL TEMPERATURE DISTRIBUTION. HOWEVER, IF TEMPERATURE DISTRIBUTION IS SKEWED TOWARD THE LOWER VALUES, THE TENDENCY FOR BELOW-AVERAGE WINDCHILL VALUES AT THE LOWER PERCENTILES WILL BE ACCENTUATED.

IN CONTRAST ARE THE STATIONS OPEN TO THE WIND FROM ALL DIRECTIONS. USUALLY THE AVERAGE WIND AT THESE STATIONS WAS HIGHER THAN THE AVERAGE OF ALL STATIONS TESTED AND TENDED TO FOLLOW A NORMAL DISTRIBUTION. THUS ALL OF THESE BIVARIATE CALCULATIONS ARE FIGURED AT A SLIGHTLY HIGHER WIND FACTOR. THE STATIONS WITH MID-CONTINENT LOCATION (EXEMPLIFIED BY CHURCHILL, DULUTH, FARGO, SIOUX FALLS, DES MOINES, MINNEAPOLIS, LA CROSS, CHICAGO,

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APPENDIX

Y TABLES

TABLE IX
WINDCHILL FACTOR

WIND-SPEED	WINDCHILL FACTOR	DIFFERENCE	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
CALM	5.56	3.71	5.931	6.302	6.673	7.044	7.415	7.786	8.158	8.529	8.900	9.271
1	9.27	1.28	9.399	9.527	9.655	9.783	9.911	10.039	10.167	10.295	10.423	10.551
2	10.55	.88	10.639	10.727	10.815	10.903	10.991	10.079	11.167	11.255	11.343	11.431
3	11.43	.78	11.509	11.587	11.667	11.745	11.823	11.901	11.979	12.057	12.135	12.213
4	12.21	.67	12.280	12.347	12.414	12.481	12.548	12.615	12.682	12.749	12.816	12.883
5	12.88	.50	12.933	12.983	13.033	13.083	13.133	13.183	13.233	13.283	13.333	13.383
6	13.38	.49	13.432	13.481	13.530	13.579	13.628	13.677	13.726	13.775	13.824	13.873
7	13.87	.42	13.915	13.957	13.999	14.041	14.083	14.125	14.167	14.209	13.251	14.293
8	14.29	.41	14.334	14.375	14.416	14.457	14.498	14.539	14.580	14.621	14.662	14.703
9	14.70	.35	14.738	14.773	14.808	14.843	14.878	14.913	14.948	14.983	15.018	15.053
10	15.05	.32	15.085	15.117	15.149	15.181	15.213	15.245	15.277	15.309	15.341	15.373
11	15.37	.30	15.403	15.433	15.463	15.493	15.523	15.553	15.583	15.613	15.643	15.673
12	15.67	.28	15.701	15.729	15.757	15.785	15.813	15.841	15.869	15.897	15.925	15.953
13	15.95	.26	15.979	16.005	16.031	16.057	16.083	16.109	16.135	16.161	16.187	16.213
14	16.21	.24	16.237	16.261	16.285	16.309	16.333	16.357	16.381	16.405	16.429	16.453
15	16.45	.22	16.475	16.497	16.519	16.541	16.563	16.585	16.607	16.628	16.651	16.673
16	16.67	.21	16.694	16.715	16.736	16.758	16.778	16.799	16.820	16.842	16.862	16.883
17	16.88	.20	16.903	16.923	16.943	16.963	16.983	17.003	17.023	17.043	17.063	17.083
18	17.08	.18	17.101	17.119	17.137	17.155	17.173	17.191	17.209	17.227	17.245	17.263
19	17.26	.17	17.280	17.297	17.314	17.331	17.348	17.365	17.382	17.399	17.416	17.433
20	17.43	.16	17.449	17.465	17.481	17.497	17.514	17.530	17.546	17.562	17.578	17.594
21	17.59	.15	17.608	17.624	17.639	17.654	17.669	17.684	17.699	17.714	17.729	17.744
22	17.74	.15	17.759	17.774	17.789	17.804	17.819	17.834	17.849	17.864	17.879	17.894
23	17.89	.15	17.909	17.924	17.939	17.954	17.969	17.984	17.999	18.014	18.029	18.044
24	18.02	.16	18.036	18.053	18.069	18.085	18.101	18.117	18.133	18.149	18.165	18.181
25	18.18	.09	18.190	18.199	18.208	18.217	18.226	18.235	18.244	18.253	18.262	18.271
26	18.27	.11										
27	18.38	.11										
28	18.49	.11										
29	18.55	.06										
30	18.68	.13										
31	18.77	.09										
32	18.85	.08										
33	18.93	.08										
34	19.01	.08										
35	19.07	.06										
36	19.13	.06										
37	19.19	.06										
38	19.26	.07										
39	19.30	.04										
40	19.35	.05										
41	19.39	.04										
42	19.43	.04										
43	19.47	.04										
44	19.50	.03										
45	19.53	.03										
46	19.56	.02										
47	19.58	.02										
48	19.60	.02										
49	19.62	.02										
50	19.63	.01										

TABLE X
PREDICTED WINDCHILL AT SELECTED PERCENTILE LEVELS

WINDCHILL INDEX	.1%	1%	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	99%	99.9%
100																	
200																	
300	0	75		115	140	170	200	240	280	320	340	370	430	485		610	800
	45	55		70	70	75	90	80	100	90	100	105	110	115		135	135
400	45	130		185	210	245	290	320	380	410	440	475	540	600		745	935
	40	55		65	70	80	90	90	90	90	100	105	120	130		125	130
500	85	185		250	280	325	380	410	470	500	540	585	660	730		870	1065
	40	55		70	70	80	80	90	90	100	100	110	120	125		130	125
600	125	240		320	350	405	460	500	560	600	640	695	780	855		1000	1190
	40	50		65	80	85	80	100	90	100	100	110	120	125		130	125
700	165	290		385	430	495	540	600	650	700	740	805	900	980		1130	1315
	45	50		65	80	85	100	90	90	100	110	105	120	120		120	130
800	210	340		450	510	580	640	690	740	800	850	910	1020	1100		1250	1445
	45	55		60	70	85	90	100	95	90	100	110	110	120		120	120
900	255	395		510	580	665	730	790	835	890	950	1020	1130	1220		1330	1565
	45	55		65	60	75	80	80	90	100	110	105	110	115		130	125
1000	300	450		575	640	740	810	870	925	990	1060	1130	1240	1335		1485	1690
	45	55		60	70	75	70	80	95	90	90	105	120	115		115	120
1100	345	505		635	710	815	880	950	1020	1080	1150	1235	1360	1450		1600	1810
	40	55		60	50	65	80	80	90	100	110	110	100	110		125	120
1200	385	560		695	760	880	960	1030	1110	1180	1260	1345	1460	1560		1725	1930
	40	55		65	80	70	80	90	90	100	100	115	120	115		125	115
1300	425	615		760	840	950	1040	1120	1200	1280	1380	1460	1580	1675		1850	2045
	35	50		60	70	95	90	90	90	90	100	110	110	110		120	110
1400	460	665		820	910	1045	1130	1210	1290	1370	1460	1570	1690	1785		1970	2155
	30	50		60	70	70	80	80	90	90	100	105	110	115		110	100
1500	490	715		880	980	1115	1210	1290	1380	1460	1560	1675	1800	1900		2080	2255
	25	35		60	60	65	70	80	85	100	100	90	100	105		120	85
1600	515	750		940	1040	1180	1280	1370	1465	1560	1660	1765	1900	2005		2200	2340
	25	30		55	40	55	60	80	80	80	100	90	100	100		95	75
1700	540	780		995	1080	1235	1340	1450	1545	1640	1740	1855	2000	2105		2295	2415
	15	20		60	40	50	60	70	85	80	80	70	80	90		80	65
1800	555	800		1055	1120	1285	1400	1520	1630	1720	1820	1925	2080	2195		2375	2480
	10	10		60	40	35	60	80	85	60	60	65	60	80		70	55
1900	565	810		1115	1160	1320	1460	1600	1715	1780	1880	1990	2140	2275		2445	2535
	5	5		40	20	30	60	40	80	40	60	60	80	70		55	40
2000	570	815		1155	1280	1350	1520	1640	1795	1840	1940	2050	2220	2345		2500	2575

NOTE: THE SECOND ROW OF FIGURES IS THE INCREMENT FOR EACH 100 INCREASE IN WINDCHILL INDEX.

TABLE XI
SUMMARY TABLE
A. DEVIATIONS FROM PREDICTIONS

	STATION	PRESS	LEAST 1%			5%			10%			20%			30%			40%			50%			60%			70%			80%			90%			MOST		
			+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-
1.	MIAMI	305	35			45			45			30			20			10			5			15			40			35			10			40			60		
2.	BROWNSVILLE	345			5			5	5										30			20			40			15			30			65			90		
O	PHOENIX	460		0			15			0		25			40			35			45			25			50			30			35			50			60			20		120
3.	SAN DIEGO	510			40	10			45			55			55			40			30						20			30			20			55			90			105			155		190
O	LAKE CHARLES	540	20				45			25			20			5			40			25			35			10			10			20			20			10			20		35
O	MONTGOMERY	540	30			75			60			60			60			40			40			30			60			85			90			110			150			130		185
●	CHARLESTON	580	15				60			45			35			20			30			20			30			10			5			35			20			25		125
O	CHATTANOOGA	630	55			5			5			25			50			25			10			15			0			10			20			5						35		40		125
●	SAN FRANCISCO	655	40				20			35			35			0			5			45			30			45			50			125			120			240		
4.	MEDFORD	700	35				10			85			100			125			110			20			0			10			20			70			80			25		
5.	ATLANTA	735			15		15			10			5			10		15			5		15			25			65			90			35			110		15			20		30
●	LITTLE ROCK	770			40	55			60			50			55			90			0			65			25			90			100			90			110			130		215		300
O	AMARILLO	815			10		20			40			30			5			20			25			5			35			40			50			60			20			145			35		
O	PORTLAND	835	130			90			30			15			0			0			5			0			0			5			10			20			5			40			10		165
O	ST. LOUIS	875	70				15		0				5		25			50			55			60			40			45			15			45			15			15		0		105
6.	OKLAHOMA CITY	895			85		25			30			35		30			5			25			40			25			60			55			60			95			135			60		
7.	NEW YORK	900			35	15			40			30			5			20			30			45			10			30			20			0			0			20			95		
O	INDIANAPOLIS	915	45				15		30			10			45			50			60			45			65			45			25			35			35			100			45		
8.	DENVER	920			75		15			5			0			20		5			5			5			0			10			20			40			35			115			30		
9.	ANNETTE IS	940	45				55		15			15			85			50			50			20						20			15			20			35			0			35		
●	SALT LAKE	945	30				60			10		60				40		50				45		55			75			60				55			70			100		100			145		
0.	SPOKANE	970	20			25			45			40			35			5			5			10			20			45				55			85			90		20			15		
1.	CLEVELAND	970	25				25		45			40			35				65		55				20			45			35			15			95			20				40		15		
O	CHICAGO	990	115			55			80			75			95			80			60			45			10			30			20			65			80			55			75		
O	POCATELLO	1020	150			150			15			65			75			55			35			5				10			30			30			65			80			10			105		
●	WATSON LAKE	1025	30				45			100			125			175			120			200			240			135			95			75			20			35			85			65		
12.	ANCHORAGE	1035	65				20			95			115			115		15				90			70			50			50			55			40			15			25			120		
O	CHEYENNE	1050	110			20			45			25			10			5				10			25			5			5				0			40			10			40			120		
13.	ST. PAUL IS	1095	55				30		5			45			90			105				35		25			0			45				10			25			25			35				135	
14.	DES MOINES	1110			80	10			80			95			70			60			10			20			30			40			55			65			80			50			10		
O	LA CROSSE	1125	210			130			90			55			20			15			20			5			20				20			10			20			65				55		
O	BILLINGS	1130	10				10			30			5			15			25			25			5			5			80			110			140			140			200		
15.	FAIRBANKS	1145	15			20				60			75			75			75			75			65			115			90			75			85			65			15			115		
16.	MINNEAPOLIS	1210	10			105			110			110			85			70			40			30			30			20			35			20			10				50					
●	CARIBOU	1230			20		105			15		45			70			40			20			35			40			25			30			25			15			35			140		
●	AKLAVIK	1230	110				25			115			120			120			95			65			145			205			235			260			285			225			235			145		
O	SIOUX FALLS	1235	145			120			150			150			145			110			80			70			85			60			35			80			90			30				160	
●	BATTLEFORD	1290			25		140			35			70			95			70			45		0			30			40			100			50			135			260			195		
●	WHITE HORSE	1300			60		165			235			250			170			100			110		135			140			150				130			30			25			50			10		
17.	DULUTH	1345	60			50			95			110			55			50			50			30			20			15			50			100			95			105			45		
18.	GALENA	1385		0			100			140			155			140			120			120			70			55			50			0				15			30			105		
●	GOOSE BAY	1400			10		105			80			30				10			10		0			10			20			10			30			60				35			30				10	
●	FARGO	1415	175			180			110			150			95			135			120			95			95			95			50			45				50			15				40	
19.	BIG DELTA	1535			50		175			240			140				120			105			100			100			95			95			55			5			15			20			45		
●	COPPERMINE	1560	10				195			305			345		25				50		30			30			100			40			80			Δ10			55				0				10	
●	HOLMAN IS	1595	140				80			250			310			375			145			165			140			45			15				30			55			0				45		
●	PORT HARRISON	1660			55		200			235			235		185			85			90			65			30			10				20			70			125			225				185	
20.	CHURCHILL	1735	5			205			205			205			155			190			125			115			80			120			100			30			15			95				40	
●	CAMBRIDGE BAY	1750			20		170			225			180		25			30			25			30			30			50			50			10			40			10				10	
●	EUREKA	1760	145			10				135			155		85			65			20			45			40			30				10			90			90			70		40		
●	MOULD BAY	1790	180				60			220			145			345			45			65			30			40			50			50			30			5			35			110		
●	RESOLUTE BAY	1845	35				55			200		80			165			115			135			80			115			95			80			5			50			30			70		
●	ISACHSENLAND	1910			35		130			365			325			430			525			205			15			65			105			155			140			100			90				0	
●	CHESTERFIELD	2075	120			5			35			145			185			140			80			15			80			90			35			50			100			115				115	
	TEST I		11	1	8	9		11	12		8	11	2	7	12	1	7	14		6	11		9	11	1	8	8	2	10	9		11	11		9	13	2	5	10	2	8	12	1	7	11		9
	TEST II		12		8	4		16	3		17	6		14	10	1	9	9		11	16	2	8	11	1	8	13		7	14	1	6	12		8	11		9	10	1	9	11	1	8	8	1	11
	TEST III		12	1	1	8		6	9	2	3	10	0	4	11	1	2	11	1	2	10		4	9	1	4	8	2	4	11		3	11	1	2	10		4	11		3	8	1	5	5		9
	COMBINED		35	2	17	21		33	24	2	28	27	2	25	33	3	18	34	1	19	31	2	21	31	3	20	29	4	21	34	1	19	34	1	19	34	2	18	31	3	20	31	3	20	24	1	29

B. OTHER PERTINENT DATA

	Station	W-C Index	Windchill-range		SUMMARY OF ERRORS						STATION INFORMATION			
					Average Error	Average "+" Error	Average "-" Error	+	0	-	Observations	Average Wind MPH	Average Temperature °F	Temperature Range °F
1.	Miami	355	37	980	36.66	41.13	23.75	11		4	6693	10.12	68.0	30 - 84
2.	Brownsville	445	31	1180	48.00	111.00	23.57	6	2	7	5951	13.19	61.5	20 - 89
O	Phoenix	460	132	895	38.33	37.50	51.66	10	2	3	3720	4.00	52.6	25 - 84
3.	San Diego	510	34	898	62.66	39.16	78.31	6		9	6696	6.23	53.7	30 - 89
O	Lake Charles	540	119	1079	24.00	16.00	31.11	5		10	3720	12.50	57.4	25 - 84
O	Montgomery	540	131	930	80.00	72.85	185.00	14		1	3720	8.30	53.7	25 - 84
●	Charleston	580	127	1039	31.66	20.00	41.66	5	1	9	7439	9.10	51.7	15 - 84
O	Chattanooga	630	191	1102	28.33	21.00	53.75	10	1	4	3720	7.10	46.2	15 - 79
●	San Francisco	655	197	1021	64.00	42.50	72.91	2	1	12	7440	9.76	47.3	25 - 69
4.	Medford	700	154	1345	49.66	30.00	57.08	2	1	12	6695	4.81	36.5	00 - 69
5.	Atlanta	705	106	1230	25.00	31.42	19.37	7		8	7436	11.48	45.9	10 - 79
●	Little Rock	710	232	1284	96.66	62.00	126.66	5	1	9	5952	9.62	44.4	10 - 84
O	Amarillo	815	222	1498	37.00	41.36	25.00	11		4	3720	13.50	40.0	0 - 79
O	Portland	835	335	1321	34.66	52.50	41.00	6	4	5	3720	11.30	36.2	- 5 - 64
O	St. Louis	875	315	1428	36.33	48.75	31.00	8	2	5	3720	12.80	36.4	- 5 - 74
6.	Oklahoma City	895	59	1650	50.00	52.26	43.75	11		4	5952	15.89	37.5	00 - 84
7.	New York	900	136	1474	25.00	24.13	55.00	11	2	2	5950	14.08	36.0	5 - 74
O	Indianapolis	915	306	1632	45.66	47.85	15.00	14		1	3720	13.20	34.2	- 5 - 74
8.	Denver	920	129	1662	25.33	29.12	29.00	8	2	5	5949	9.36	29.3	-25 - 74
9.	Annette Is	940	162	1757	34.33	40.50	27.50	10	1	4	7427	12.27	31.8	- 5 - 49
●	Salt Lake	945	303	1472	63.66	46.66	67.91	3		12	6696	8.52	28.3	-20 - 59
10.	Spokane	970	306	1709	34.33	24.37	45.71	8		7	6696	8.29	24.2	-25 - 54
11.	Cleveland	970	136	1648	36.00	37.50	33.00	10		5	5952	13.07	30.6	-10 - 74
O	Chicago	990	410	1753	58.00	58.00	.00	15		0	3720	11.20	27.4	-15 - 69
O	Pocatello	1020	460	1611	60.00	71.25	47.14	8		7	3720	11.70	26.0	-15 - 59
●	Watson Lake	1025	342	1785	103.00	71.66	120.90	4		11	914	2.17	4.3	-60 - 44
12.	Anchorage	1035	312	2044	62.66	55.00	65.00	4		11	7437	4.75	10.2	-40 - 49
O	Cheyenne	1050	313	1869	31.33	43.75	24.00	9	1	5	3720	15.90	28.6	-25 - 64
13.	St. Paul Is	1095	363	1666	44.33	46.87	48.33	8	1	6	1483	18.01	27.4	- 5 - 44
14.	Des Moines	1110	242	1836	47.33	45.71	80.00	14		1	7440	12.71	21.5	-15 - 59
O	La Crosse	1125	565	1782	50.33	52.30	37.50	13		2	3720	9.40	15.2	-35 - 49
O	Billings	1130	363	2043	53.66	97.85	15.00	7		8	3720	12.00	19.4	-30 - 69
15.	Fairbanks	1145	383	2023	71.66	64.66	73.75	3		12	7424	2.63	-12.1	-50 - 39
16.	Minneapolis	1210	329	1897	49.00	52.69	50.00	13	1	1	7433	11.27	13.3	-30 - 49
●	Caribou	1230	373	2105	44.00	43.33	46.66	12		3	5949	12.70	13.8	-35 - 54
●	Aklavik	1230	507	2180	159.00	191.00	95.00	10		5	959	5.68	-1.8	-50 - 24
O	Sioux Falls	1235	547	1812	100.66	96.42	165.00	14		1	3720	11.40	11.7	-30 - 49
●	Battleford	1290	396	2230	89.33	115.71	75.71	7	1	7	436	8.22	1.5	-50 - 44
●	White Horse	1300	365	2038	117.33	28.33	139.58	3		12	744	10.19	5.6	-60 - 44
17.	Duluth	1345	423	2140	62.00	62.00	.00	15		0	5950	13.30	7.5	-35 - 39
18.	Galena	1385	383	2224	81.33	67.50	98.63	2	2	11	6826	5.99	-12.0	-60 - 39
●	Goose Bay	1400	452	2144	34.00	32.85	40.00	7	1	7	6664	10.79	+ .02	-35 - 44
●	Fargo	1415	690	2208	98.66	106.92	45.00	13		2	6696	13.30	3.6	-35 - 44
19.	Big Delta	1535	312	2335	90.00	21.25	115.90	4		11	7424	12.25	- 5.8	-60 - 49
●	Coppermine	1560	515	2257	91.66	52.22	190.00	9	1	5	898	8.84	-16.5	-55 - 14
●	Holman Is	1595	657	2242	126.00	77.50	157.72	2	1	12	124	8.78	-17.8	-45 - 09
●	Port Harrison	1660	475	2202	121.00	77.50	150.00	6		9	1240	12.76	-13.1	-45 - 29
20.	Churchill	1735	453	2400	115.00	131.25	50.00	11		4	2945	15.27	-13.6	-50 - 29
●	Cambridge Bay	1750	524	2442	60.33	30.00	121.00	10		5	560	10.52	-23.7	-55 - 19
●	Eureka	1760	696	2493	68.66	53.33	91.66	9		6	1488	6.35	-37.4	-60 - 24
●	Mould Bay	1790	735	2585	94.00	58.88	146.66	9		6	1115	9.16	-30.0	-60 - 09
●	Resolute Bay	1845	597	2577	87.33	97.50	67.00	11		4	1239	10.41	-29.9	-55 - 24
●	Isachsenland	1910	529	2540	179.00	91.66	253.75	6	1	8	1226	10.53	-34.1	-60 - 19
●	Chesterfield	2075	696	2490	87.33	84.54	95.00	11		4	958	15.19	-34.3	-50 - 34
	Test I							164	12	124				
	Test II							144	8	148				
	Test III							144	10	56				

TABLE XII
SUMMARY OF AVERAGE ERRORS FOR THE MODEL, EACH OF THE SEPARATE TESTS, AND THE COMBINED TESTS

	Least			1%			5%			10%			20%			30%			40%			50%			60%			70%			80%			90%			95%			99%			Most			Summary			Total
	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	+	0	-	
Model(1)	11	1	8	9	11		12		8	11	2	7	12	1	7	14		6	11		9	11	1	8	8	2	10	9		11	11		9	13	2	5	10	2	3	12	1	7	11		9	164	12	124	300
Test II	12		8	4	16		3		17	6		14	10	1	9	9		11	10	2	8	11	1	8	13		7	14	1	5	12		8	11		9	10	1	9	11	1	8	8	1	11	144	8	148	300
Test III	12	1	1	8	6		9	2	3	10	0	4	11	1	2	11	1	2	10		4	9	1	4	8	2	4	18		3	11	1	2	10		4	11		3	8	1	5	5	1	9	144	10	56	210
Test II & III	24	1	9	12	22		12	2	20	16		18	21	2	11	20	1	12	20	2	12	20	2	12	21	2	11	25	1	8	23	1	10	21		13	21	1	12	21	2	13	13	1	20	288	18	204	510
Combined	35	2	17	21	33		24	2	28	27	2	25	33	3	19	34	1	19	31	2	21	31	3	20	29	4	21	34	1	19	34	1	19	34	2	18	31	3	20	31	3	20	24	1	29	452	30	328	810

		Least	1%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	99%	Most	Average
Model(1)	+	33.63	53.18	61.25	74.09	63.33	45.71	38.63	36.81	30.00	41.11	43.18	38.54	50.50	64.58	78.18	51.25
	-	45.62	43.18	83.12	89.25	86.42	84.16	81.25	56.87	49.00	45.00	43.33	42.50	49.37	60.71	73.33	52.57
	Ave	36.75	48.00	70.00	72.00	68.25	57.25	53.75	43.00	36.50	43.25	43.25	42.25	45.00	60.00	76.00	52.51
Test II	+	85.83	62.50	68.33	88.33	100.00	82.22	63.00	51.36	68.46	63.57	68.75	71.56	65.50	79.09	96.87	74.68
	-	93.12	101.00	156.17	168.57	196.66	108.63	106.87	88.75	77.14	91.00	59.37	66.66	89.44	115.00	115.00	111.45
	Ave	64.75	93.25	143.50	144.50	138.50	96.75	74.25	63.75	71.50	67.25	65.00	69.25	73.00	89.50	102.00	90.83
Test III	+	90.83	80.62	56.11	52.50	51.81	44.09	43.00	39.44	43.75	32.27	41.81	46.00	58.18	84.39	95.00	55.69
	-	10.00	20.00	31.66	15.00	20.00	32.50	16.25	20.00	7.50	20.00	25.00	31.25	43.33	86.00	117.22	37.76
	Ave	78.57	54.64	42.85	41.78	43.57	39.28	35.35	31.07	30.71	29.64	36.42	41.79	55.00	57.50	109.28	48.26
Test II & III	+	88.53	74.58	59.16	65.93	74.76	61.25	53.00	46.25	59.00	49.80	60.21	59.28	61.66	73.57	96.15	65.19
	-	30.50	78.86	137.50	134.44	162.72	105.00	76.66	65.83	51.81	63.75	52.50	57.76	77.91	80.76	116.50	91.22
	Ave	70.44	77.35	101.78	102.20	98.82	73.08	58.23	50.44	53.23	51.76	56.17	57.44	65.58	76.32	105.29	73.30
Combined	+	71.14	65.90	58.95	69.95	70.60	54.85	47.90	43.22	51.03	47.50	54.70	51.47	58.06	74.83	87.91	60.13
	-	37.64	56.96	121.96	121.80	133.05	92.89	66.19	62.30	50.47	53.21	48.15	55.16	66.50	73.75	103.10	79.19
	Ave	57.96	66.48	89.44	91.01	87.50	67.22	53.24	47.87	47.03	48.62	51.38	52.12	57.96	70.18	94.40	65.61

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Dept. of the Navy, Wash 25, D. C.
Attn. Code 33

NAVY (Cont)

1 Commander, U. S. Naval Ord. Test
Station, China Lake, Calif.
Attn: Code 753

1 Chief, Bureau of Aeronautics
Dept. of the Navy, Wash 25, D. C.
Attn: Code AE 52

1 Chief, Bureau of Supplies & Accounts
Department of the Navy
Washington 25, D. C.

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1 C.G., U.S. Continental Army Command
Ft. Monroe, Va.

1 President
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Ft. Sill, Okla.
Attn: ATEA

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Ft. Knox, Ky.
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Attn: Advisory Bd. on QM R&D

10 Armed Services Technical Information Agency
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Arlington 12, Va.
Attn: TIPDR

2 Gift and Exchange Division
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Washington 25, D. C.

1 U. S. Department of Commerce
Weather Bureau Library, Washington, D.C.

1 Central Intelligence Agency
Collection & Dissemination
Washington 25, D.C.

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1 Generalintendanten
Standardiseringskontoret
Festningen
Oslo, Norway

1 Marine Corps Equipment Board
Marine Development Center
Marine Corps School
Quantico, Va.

1 Office of Technical Services
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Washington 25, D.C.
Attn: Tech Rpts Sec (THRU OQMG)

1 U. S. Department of Agriculture Library
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Industrial College of the Armed Forces
Ft. McNair, Washington 25, D. C.

1 QM Representative
Army Command and General Staff College
Department of the Infantry Div.
Ft. Leavenworth, Kansas

WINDCHILL PREDICTION CHART

EXPLANATION ON USE OF CHART

BY A SIMPLE TECHNIQUE, IT IS POSSIBLE TO ESTIMATE THE PROBABILITY OF A SPECIFIED LEVEL OF WINDCHILL. DATA REQUIRED (MEAN MONTHLY AIR TEMPERATURE AND WINDSPEED) ARE ENTERED IN THE SIPLE WINDCHILL NOMOGRAM AT THE LEFT AND A WINDCHILL INDEX OBTAINED. THIS INDEX IS TRANSFERRED TO THE PREDICTION CHART AT THE RIGHT AND FOLLOWED TO THE PREDETERMINED LEVEL DESIRED (READ ON ACTUAL WINDCHILL SCALE AT THE EXTREME RIGHT). PERCENTAGE FREQUENCY CAN BE READ ON THE PROBABILITY SCALE AT EITHER TOP OR BOTTOM OF THE PREDICITION CHART.

EXAMPLE: AT FORT CHURCHILL, JANUARY MEAN TEMPERATURE (-18°F) AND WINDSPEED (14.9 MPH) ENTERED IN THE NOMOGRAPH AT THE LEFT GIVE AN 1,800 WINDCHILL INDEX. THIS 1,800 INDEX INTERSECTS THE 1,400 ACTUAL WINDCHILL (CONDITION AT WHICH EXPOSED FLESH FREEZES) AT 72 PERCENT ON THE UPPER SCALE OR 28 PERCENT ON THE LOWER SCALE, INDICATING THAT DANGER OF FREEZING IS A PROBABILITY 72 PERCENT OF THE TIME AT CHURCHILL DURING JANUARY SAFETY FROM FREEZING IS A PROBABILITY 28 PERCENT OF THE TIME. THE POSSIBILITY OF THE SITUATION BECOMING DANGEROUS FOR TRAVEL OR LIVING IN TEMPORARY SHELTERS (2,000 ACTUAL WINDCHILL) IS A PROBABILITY 16 PERCENT OF THE TIME.

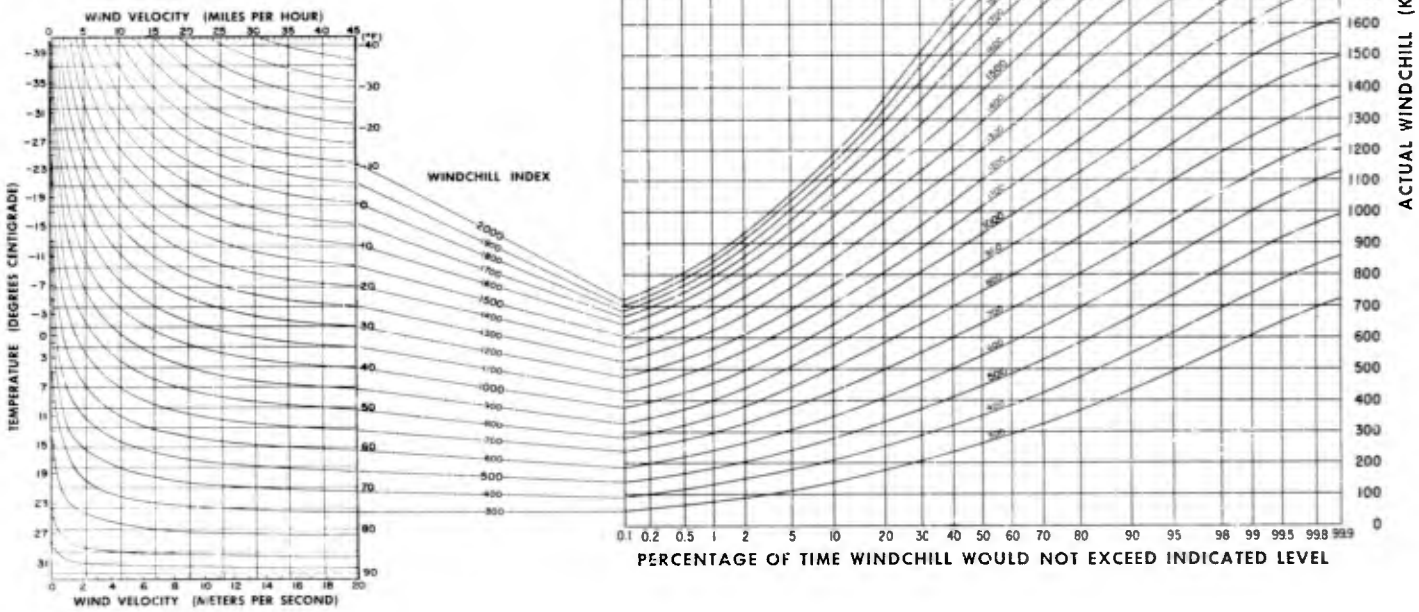

FIGURE 5: WINDCHILL PREDICTION CHART

WINDCHILL PREDICTION CHART

EXPLANATION ON USE OF CHART

BY A SIMPLE TECHNIQUE, IT IS POSSIBLE TO ESTIMATE THE PROBABILITY OF A SPECIFIED LEVEL OF WINDCHILL. DATA REQUIRED (MEAN MONTHLY AIR TEMPERATURE AND WINDSPEED) ARE ENTERED IN THE SIPLE WINDCHILL NOMOGRAM AT THE LEFT AND A WINDCHILL INDEX OBTAINED. THIS INDEX IS TRANSFERRED TO THE PREDICTION CHART AT THE RIGHT AND FOLLOWED TO THE PREDETERMINED LEVEL DESIRED (READ ON ACTUAL WINDCHILL SCALE AT THE EXTREME RIGHT). PERCENTAGE FREQUENCY CAN BE READ ON THE PROBABILITY SCALE AT EITHER TOP OR BOTTOM OF THE PREDICITION CHART.

EXAMPLE: AT FORT CHURCHILL, JANUARY MEAN TEMPERATURE (-38°F) AND WINDSPEED (14.9 MPH) ENTERED IN THE NOMOGRAPH AT THE LEFT GIVE AN 1,800 WINDCHILL INDEX. THIS 1,800 INDEX INTERSECTS THE 1,400 ACTUAL WINDCHILL (CONDITION AT WHICH EXPOSED FLESH FREEZES) AT 72 PERCENT ON THE UPPER SCALE OR 28 PERCENT ON THE LOWER SCALE, INDICATING THAT DANGER OF FREEZING IS A PROBABILITY 72 PERCENT OF THE TIME AT CHURCHILL DURING JANUARY. SAFETY FROM FREEZING IS A PROBABILITY 28 PERCENT OF THE TIME. THE POSSIBILITY OF THE SITUATION BECOMING DANGEROUS FOR TRAVEL OR LIVING IN TEMPORARY SHELTERS (2,000 ACTUAL WINDCHILL) IS A PROBABILITY 16 PERCENT OF THE TIME.

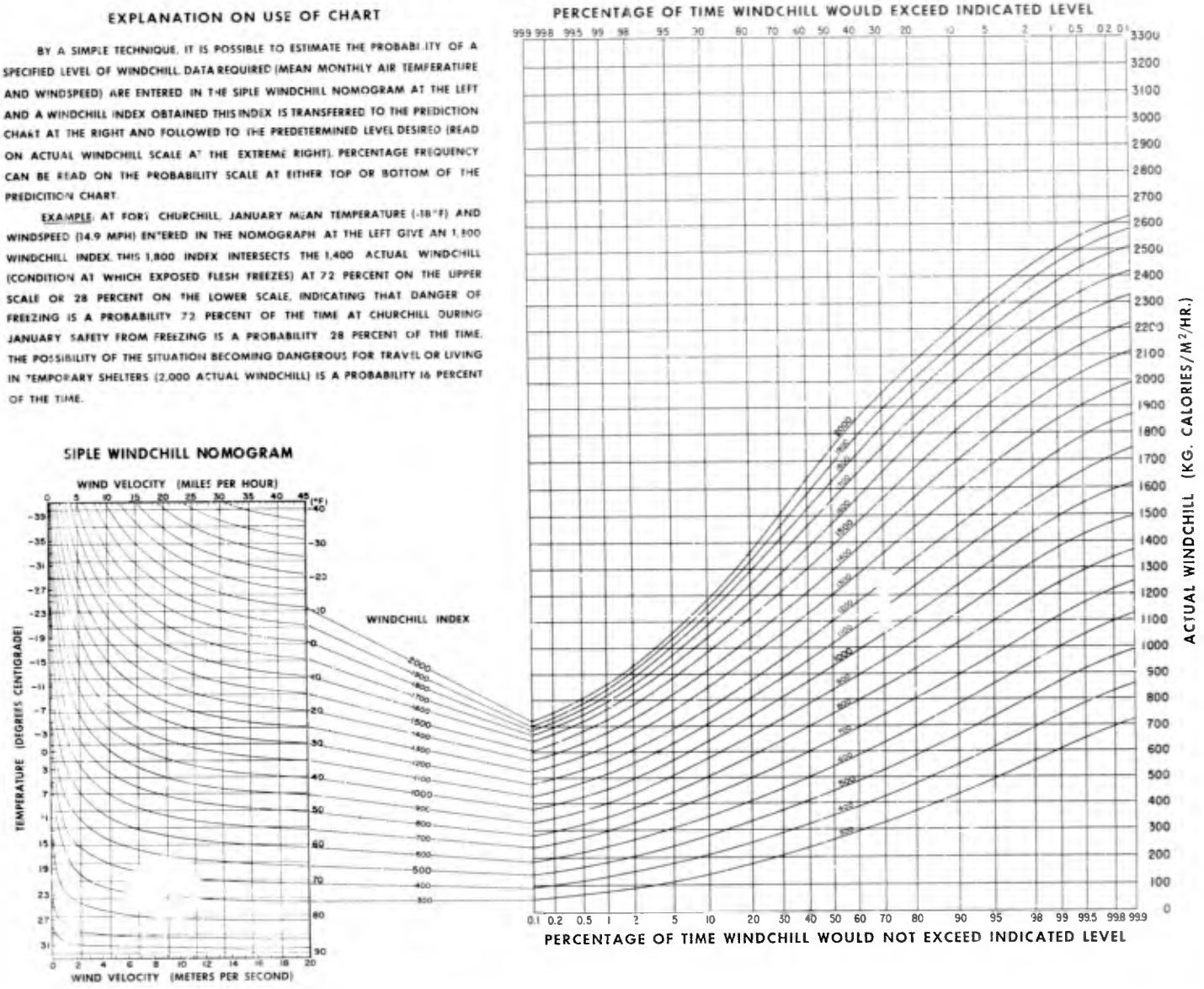

FIGURE 5: WINDCHILL PREDICTION CHART

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